ATTACHMENT 7 – ECONOMIC ANALYSIS – WATER SUPPLY COSTS AND BENEFITS

APPENDIX O

Kaweah Delta WCD 2007 Water Resources Investigation

FUGRO WEST, INC.

WATER RESOURCES INVESTIGATION OF THE KAWEAH DELTA WATER CONSERVATION DISTRICT

FINAL REPORT

Prepared for:
Kaweah Delta
Water Conservation District

December 2003
(Revised July 2007)

FUGRO WEST, INC.

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October 5, 2007
Project No. 3087.004.07

Kaweah Delta Water Conservation District
Post Office Box 1247
Visalia, California 93279

Attention: Mr. Larry Dotson, Senior Engineer

FINAL REPORT
Water Resources Investigation of the Kaweah Delta Water Conservation District

Dear Mr. Dotson:

Fugro West, Inc. is pleased to submit this FINAL REPORT of the Kaweah Delta Water Conservation District (District), which incorporates various revisions to the earlier Water Resources Investigation dated December 5, 2003. The revisions for the most part involved adjustments to surface water delivery and crop water usage estimates used in the inventory method to determine changes of groundwater in storage. The overall conclusions of the original investigation remain unchanged.

It has been a pleasure and a challenge to incorporate the revisions into the original investigation, which we know is of utmost importance to the District and its constituents. We will remain available at your convenience to discuss this report or to answer any questions.

Sincerely,

FUGRO WEST, INC.

Timothy G. Nicely

Timothy Nicely, P.G.
Project Hydrogeologist

D Gardner

David A. Gardner, C.Hg.
Principal Hydrogeologist

Copies Submitted: (25) Addressee, 1 CD-ROM with Adobe PDF file

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APPENDICES

LIST OF ACRONYMS

AEG	Association of Engineering Geologists
B&E	Bookman & Edmonston
BLM	U.S. Bureau of Land Management
Cal Water	California Water Services Company
CDMG	California Division of Mines and Geology
CIMIS	California Irrigation Management and Information System
CVP	Federal Central Valley Project
District	Kaweah Delta Water Conservation District
DOGGR	Department of Conservation Division of Oil and Gas and Geothermal Research
DWR	State Department of Water Resources
EPA	United States Environmental Protection Agency
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
KHD	Kings County Health Department
LDC	Legacy Data Center
MS	Microsoft
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
RWQCB	Regional Water Quality Control Board-Central Valley Region
SCE	Southern California Edison
SSE	Soils Suitability Extension
SSURGO	Soil Survey Geographic Database
SWP	State Water Project
TEHD	Tulare County Environmental Health Department
TID	Tulare Irrigation District
TRC	Technical Review Committee
TRMA	Tulare County Resources Management Agency-Solid Waste Division
USGS	United States Geological Survey
VPWD	City of Visalia Public Works Department
WRI	Water Resources Investigation

ORGANIZATION

KAWEAH DELTA WATER CONSERVATION DISTRICT
Visalia, California

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Mark Watte, Vice-President
Bruce George, Secretary

Board of Directors

Division 1 – Chris Tantau

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Acknowledgments

During the course of this investigation, valuable information and assistance were obtained from a great number of individuals and agencies. These contributions are gratefully acknowledged.

Special mention is made of the Technical Review Committee (TRC), who met on a periodic basis to review and discuss the interim reports. The TRC participants are listed below.

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EXECUTIVE SUMMARY

GENERAL

This Final Report of Water Resources Investigation (WRI) of the Kaweah Delta Water Conservation District presents the results of efforts to investigate and quantify the water resources of the District. The work was conducted jointly by Fugro West, Inc. and in conjunction with Keller Wegley Associates, and Peter Canessa, P.E.

The WRI was a technical investigation intended to provide the District, public water agencies, and overlying landowners and water users a better understanding of the District by answering questions related to the quantity of groundwater in the District, the hydraulic movement of groundwater through the District, sources and volumes of natural recharge, and trends in water levels. Although this investigation does not address specific planning or water management issues, it provides the foundation that the District needs to continue its water resource planning efforts.

The District, with a total area of 340,000 acres, has reached a high degree of development, with about 285,000 acres devoted to a variety of irrigated crops and with approximately 40,000 acres of urbanized area largely in and around the cities of Tulare and Visalia. There are 15,000 acres of presently undeveloped land in the District of which minimal acreage is considered suitable for the production of irrigated crops.

At the present time, about 862,000 acre-feet (af) of water per year are delivered for irrigation, municipal and industrial and related uses. Use of water by irrigated agriculture comprises more than 94 percent of the total, or 809,000 acre-feet per year (afy). Irrigation requirements are met from both surface and groundwater sources, while municipal and industrial supplies are obtained solely from groundwater.

Usable groundwater is found in waterbearing deposits throughout the District in complex aquifer systems. In the easterly part of the District, these systems are largely unconfined or semiconfined. Confined groundwater is found in aquifer systems underlying the westerly portion of the District. Groundwater storage in the unconfined and semiconfined aquifers provides the cyclical regulation of the District's water supplies, and it is estimated that about 1.5 million af of groundwater storage capacity are currently being utilized in this function.

The most significant subsurface feature in the District affecting the occurrence and movement of groundwater is the Corcoran Clay, a relatively impervious stratum, the eastern edge of which follows generally a north-south line about 2 to 3 miles east of U.S. Highway 99. The Corcoran Clay dips to the west and usable groundwater is found both above and below this stratum. The areas between the easterly edge of the Corcoran Clay and the Rocky Hill fault have been designated as Hydrologic Units II, III, and IV, and groundwater in these units is found in unconfined alluvium and semiconfined continental deposits underlying the alluvium.

Groundwater moves generally in a southwesterly direction along the principal axis of the District. Outflow of groundwater from the District occurs to the west from Hydrologic Unit VI. Outflow also occurs from Unit IV to the south. Inflow of groundwater to the District occurs both from the north and from the south into Unit VI in response to a pumping depression in aquifers above the Corcoran Clay.

The chemical quality of both surface water and groundwater in the District is generally satisfactory for irrigation, and municipal and industrial use. Although some deterioration of quality may occur over time with the continued use and reuse of groundwater, the quality of groundwater is expected to remain satisfactory in view of the excellent quality of the replenishment water. Only in Hydrologic Unit VI does the potential exist for significant increases in groundwater salinity.

A water budget was performed over a defined base period (1981-1999) by assessing the components of inflow and outflow of water within the District, and calculating the change in groundwater storage. The water budget was performed by calculating each component of water inflow and outflow for each year of the base period for the entire District and for each of the six hydrologic units, and comparing the totals to the annual change in groundwater in storage, as determined by the specific yield method.

The hydrologic budget is simply a statement of the balance of total water gains and losses from the District. In very simple terms, the hydrologic budget is summarized by the following equation:

Inflow = Outflow ($\pm$) Change in Storage

where Inflow equals:

- Percolation of precipitation
- Streambed percolation and delivered water conveyance losses
- Subsurface inflow
- Percolation of applied irrigation return
- Percolation of wastewater, and
- Artificial recharge; and

Outflow equals:

- Groundwater pumpage
- Subsurface outflow
- Extraction by phreatophytes, and
- Exported water.

Using the inventory method described above, the sum of all the components of outflow from the entire District exceeded the sum of all the components of inflow by an estimated 21,700 afy, for an accumulated storage depletion of about 413,000 af over the base period. Given a useable basin storage volume of about 2,500,000 af (historic high to historic low water levels), the deficit of 413,000 afy over the 19-year base period equals about 17 percent of the total groundwater in storage.

Water supply deficiencies were apparent during the late 1980s. Surpluses, however, occurred during the early 1980s (1982 and 1983) and 1990s (1993, 1995 and 1998). During these periods, seasonal surpluses of greater than 700,000 afy occurred. The periods of water supply surplus and deficiency are generally consistent with the seasonal and cyclic pattern of precipitation and surface water supply that occurred during the base period. For the District as a whole, streambed percolation and conveyance loss was the greatest component of inflow (34 percent), followed by percolation of irrigation at about 29 percent and percolation of precipitation at 16 percent.

The safe or perennial yield of the District is provided in this Final Report. It is defined as the volume of groundwater that can be pumped year after year without producing an undesirable result. Any withdrawal in excess of safe yield is considered overdraft. The "undesired results" are recognized to include not only the depletion of groundwater reserves, but also deterioration in water quality, unreasonable and uneconomic pumping lifts, creation of conflicts in water rights, land subsidence, and depletion of streamflow by induced infiltration. It should be recognized that the concepts of safe yield and overdraft imply conditions of water supply and use over a long-term period. Given the importance of the conjunctive use of both surface water and groundwater in the District, short-term water supply differences are satisfied by groundwater pumpage, which in any given year, often exceeds the safe yield of the District and individual hydrologic units.

Under the current conditions of development and water supply, it is apparent that the District as a whole is in a condition of overdraft. The magnitude of the overdraft is in the range of about 21,700 to 36,000 afy (inventory versus specific yield method), and occurs in the west side of the District. To the extent that groundwater is exported out of the District from Hydrologic Unit No. V, this estimated overdraft would increase.

The present overdraft in the District is compared to earlier work of B&E (1972). The overdraft is manifested as a progressive lowering of water levels and such declining water levels are most evident in Hydrologic Unit No. VI. Generally, the decline in water levels in this area have been about 5 feet per year over the base period, but this varies widely depending on location, seasonal imbalances in water supply (i.e., wet versus dry cycles within the base period), and where pumping (well fields) is concentrated. The rate of decline in this area is not as severe as predicted by B&E (1972), which was stated at about 10 feet per year, on average. The magnitude of the overdraft by B&E (1972) was considerably greater under future (ultimate) conditions of development, and was estimated at about 110,000 afy. Of this amount, 104,000 afy was predicted in Hydrologic Unit No. VI alone.

It is recommended that a basin-wide numerical groundwater flow model be developed for the District. The model will serve as a tool for quantitative evaluation of existing and future hydraulic conditions across the District, including changing groundwater level elevations, well yields, natural and artificial recharge, and associated effects on surface water-groundwater interactions. Specifically, the objectives of the model include:

- Refining uncertain components of the hydrologic budget for the District;
- Refining estimates of safe yield for the District;
- Evaluating potential impacts on groundwater levels and safe yield as a result of continued and varied basin operations and hydraulic conditions; and
- Defining operational options for comprehensive and/or localized management of groundwater use across the District.

CHAPTER 1 - INTRODUCTION, DATA SUMMARY AND BASE PERIOD DEFINITION

1.1 INTRODUCTION

1.1.1 Introduction and Background

The water supply resources of the Kaweah Delta Water Conservation District (District) have been the focus of numerous studies and reports over the last 50 years. Many of the earlier reports were prepared with emphasis on supplemental water requirements for the District related to surface water flows and diversions. The most comprehensive study, which integrated the conjunctive supply of both the surface and groundwater of the District, was conducted by Bookman and Edmonston (B&E) in the early 1970s (B&E, 1972). Since that time, the District, in conjunction with the State Department of Water Resources (DWR), has issued various annual reports on water supply; however, such reports have been somewhat narrowly focused on water level data and conditions of groundwater in storage in the District.

Since 1972, the District has experienced modest changes in land use more or less consistent with projections of ultimate development and water demand described by B&E (1972). Predictions of water level declines related to District-wide imbalances in water supply and demand (and overdraft) made by B&E were significant. The District annual reports unfortunately have provided a limited ability to validate the B&E forecasts which, particularly given water resources management efforts and the availability of supplemental sources of supply to the District over the intervening 30 years, may have offset the magnitude of the estimated overdraft.

1.1.2 Purpose and Scope

The Water Resources Investigation (WRI) of the District was formally initiated in December 2001. The purpose of the study was to conduct a detailed geologic and hydrogeologic investigation and analysis to evaluate and assess the safe yield of the District. The overall purpose of the study is to provide the District, overlying water purveyors and Tulare County planning agencies with foundational data that will enable them to plan for future water supply development and optimize both immediate and long-term water supply programs.

This final report presents a comprehensive and detailed description of the District. The scope of the WRI was generally divided into tasks, which included:

- Task 1 presented the results of collecting, compiling, and reviewing available data and the establishment of a base period for purposes of analyses;
- Task 2 presented a geologic and hydrogeologic evaluation of oil well logs, water well logs, geologic mapping, and fault investigations which resulted in delineation of the lateral and vertical extent of the basin and the definition of hydrologically distinct units;

- Task 3 reported on the aquifer characteristics and hydraulic parameters across the District that were subsequently used to estimate various components of the hydrologic budget (storage changes);
- Task 4 involved the compilation and review of surface water delivery data and conveyance losses in the river and canals.
- Task 5 involved collection and evaluation of water quality data throughout the District;
- Task 6 consisted of preparation of a hydrologic budget and calculation of the safe yield of the District; and
- Task 7 consisted of the preparation of a final report to document the results of each of the prior tasks.

The conclusion of each task was followed by presentation of an Interim Report, which presented the findings of each task and provided an opportunity for review and public comment throughout the process. This final report is generally organized to be consistent with the interim reports, each of which forms a chapter of this final report.

The WRI was conducted by a consultant team, coordinated by the District. An eight-member Technical Review Committee (TRC) was appointed by the District to provide guidance to the consultant team and provide oversight throughout the study through a series of meetings held every several months (sometimes by teleconference). The consultant team and TRC members included:

a. Prime Consultant:

   - Fugro West, Inc. - Project Management, Hydrogeology, Geotechnical Information Systems (GIS), and Administrative Support
     - David Gardner, Principal Hydrogeologist
     - Paul Sorensen, Senior Hydrologist
     - Timothy Nicely, Staff Hydrogeologist

b. Subconsultants:

   - Keller/Wegler, Consulting Engineer
     - Dennis Keller, Civil Engineer
     - Gene Winsett, Engineering Technician
   - Peter Canessa, P.E. - Agricultural Water Demand and Land Use
     - Peter Canessa, Agricultural Engineer

c. District Staff:

   - Larry Dotson, P.E. - Project Manager and Senior Engineer

d. Technical Review Committee:

- Thomas Harter, Ph.D., University of California Agricultural Extension - Department of Land, Air and Water Resources
- Paul Hendrix, Assistant Manager - Tulare Irrigation District
- Mike Whitlock, County of Tulare, Resource Management Agency
- John Dutton, City Engineer - City of Visalia, Public Works
- Ken Ramage, Assistant City Engineer - City of Tulare, Public Works
- Thomas Salzano, Water Resources Planning Supervisor - California Water Service Company
- Richard L. Schafer, Consulting Engineer - R.L. Schafer & Associates
- Kimball Loeb, Consultant - EnviroSolve

1.2 DESCRIPTION OF THE DISTRICT

1.2.1 General Features

The District was formed in 1927 under provisions of the Water Conservation District Act of 1927 for the purpose of conserving and storing waters of the Kaweah River and of conserving and protecting the underground waters of the Kaweah Delta.

The District is located in the south-central portion of the San Joaquin Valley of California and, as shown on Plate 1 - Study Area Location Map, lies both in Tulare and in Kings Counties. The total area of the District is about 340,000 acres, with approximately 255,000 acres located in the westerly portion of Tulare County and the balance, or about 82,000 acres, in the northeasterly corner of Kings County. As indicated on Plate 2 - Study Area Map, the District boundaries are for the most part coincident with the DWR Kaweah Basin (Unit I232), which is a subset of the larger San Joaquin Valley Hydrologic Unit. The Kaweah basin boundaries are generally similar to the District boundaries except for areas to the east and a small portion in the southwest corner of the District (near Corcoran, which falls within the Tulare Lake basin). For purposes of the WRI, it is important to note that the study area is the District, which in turn has traditionally been subdivided into six hydrologic units. While the term basin may from time to time be used, it should be taken as synonymous with the District boundaries. Moreover, it should be noted that the District boundaries are administrative and political in nature (i.e., township, county lines, etc.) and, for the most part, have no hydrogeologic significance.

District lands are primarily agricultural in nature, although the cities of Visalia and Tulare constitute significant areas of urbanization. Farmersville is the other incorporated area. Smaller unincorporated rural communities include Goshen, Ivanhoe, Waukena, and Guernsey. A high degree of development exists in the District, with approximately 265,000 acres presently devoted to the production of a variety of irrigated crops and with about 45,000 acres of urbanized land.

U.S. Highway 99 is a principal traffic artery through the San Joaquin Valley and crosses the middle of the District in a north-south direction. The main line of the Southern Pacific Railroad similarly crosses the District in a north-south direction adjacent to Highway 99. The main line of the Atchison-Topeka and Santa Fe Railroad also traverses the District in a north-south direction near its westerly boundary, as does State Highway 43.

The District encompasses the alluvial fan of the Kaweah River, extending about 40 miles in a southwesterly direction from the foothills of the Sierra Nevada on the east to the central axis of the San Joaquin Valley in the vicinity of the Tulare Lake bed on the west. The District is generally bounded on the west by the service area of the Kings County Water District and on the south by the service area of the Lower Tule River Irrigation District. Its maximum dimension in the north-south direction is about 24 miles.

At McKay Point, a significant geographical feature immediately to the east of the eastern District boundary and about 1-1/2 miles west of the community of Lemon Cove, the Kaweah River divides into the St. Johns River and Lower Kaweah River branches, and enters the District in these two channels. Within the District, the Lower Kaweah branch divides into several distributaries.

Numerous public and private entities within the District divert water for irrigation from the Kaweah River and its distributaries. About 250,000 acres within the District have access to surface water supplies from the river system. Because of the erratic nature of flow in the Kaweah River, which varies substantially in magnitude from month to month and from year to year, nearly all of these lands obtain supplemental irrigation from groundwater. All municipal and industrial uses within the District are supplied from groundwater.

Terminus Dam and Reservoir, located on the Kaweah River about 3-1/2 miles to the east of the District, was completed in 1961 by the U.S. Corps of Engineers. This project was constructed for purposes of flood control on the Kaweah River and to provide river control for irrigation purposes. The dam is an earthfill structure about 250 feet in height, with a reservoir capacity of about 142,500 acre-feet (af). The District has a contract with the United States for repayment under Reclamation Law of the portion of the project costs allocated to conservation purposes. Terminus Dam is undergoing enlargement, with scheduled completion in late 2003. The enlargement is anticipated to provide an additional 8,500 acre-feet per year (afy) of irrigation water supply for the District (Kaweah River Basin Investigation, U.S. Army Corps of Engineers, 1996).

The Friant-Kern Canal, a feature of the Federal Central Valley Project (CVP), traverses the easterly portion of the District, delivering San Joaquin River water stored in Millerton Lake located to the north. The Tulare Irrigation District (TID), which lies entirely within the District, obtains water from Friant-Kern Canal under a long-term contract with the United States. Although the TID is the only entity within the District with a long-term contract for CVP water, the District itself, as well as other entities, historically has received CVP water from time to time that was surplus to the needs of long-term Friant Division contractors.

In common with other areas along the east side of the San Joaquin Valley, the District historically has experienced the anomaly of flood control problems coupled with water deficiency. From time to time, flows in Kaweah River reach damaging levels within the District, with substantial volumes of water escaping to flood vulnerable agricultural land in Tulare Lake bed. Terminus Reservoir has provided a high degree of river control by substantially reducing the frequency of flood damage and by regulating seasonal runoff to irrigation demands. However, total flood control of the Kaweah River system has not been achieved, as dramatically shown by the damaging flood of 1969.

1.3 DELINEATION OF HYDROLOGIC UNITS

1.3.1 Overview

As discussed by B&E (1972), there is a practical value for analytical purposes in dividing the approximate 340,000-acre District area into hydrologic units. Although there are no significant, distinct structural boundaries that interrupt the subsurface flow of groundwater within the District, there are differences in the bulk aquifer properties, aquitard deposits, sources of recharge, land use, and water level conditions (confined v. unconfined areas) that warrant dividing the District into hydrologic units. The hydrologic unit boundaries developed by B&E have merit, but have been modified in light of current conditions of surface water conveyance and deliveries to better account for the complex nature of the deliveries.

B&E subdivided the District into six hydrologic units to facilitate the quantitative analysis of water supply and use. Boundaries were established "primarily" on the basis of the subsurface geologic features, which affect the occurrence and movement of groundwater (e.g., the occurrence of the E Clay) and, to a lesser degree, on the conveyance and distribution of surface water within the District. The latter issue relates to water service areas and the location of major entitlement holders. Table 1 - Revised District Hydrologic Units, provides a comparison of the earlier B&E hydrologic unit boundaries and the hydrologic unit boundaries used in this report. Kaweah Hydrologic Unit Boundary Changes (see Figure 1) shows the former and current boundaries.

Table 1. Revised District Hydrologic Units

Hydrologic Unit No.	General Geographic Designation	B&E (1972)	Fugro
		Area in Acres	
I	Eastern	17,674	16,250
II	St. Johns	38,843	49,503
III	Visalia	21,708	35,457
IV	Outside Creek	45,520	73,818
V	Tulare	91,356	81,679
VI	Western	123,472	83,344
	Totals:	**338,570**	**340,051**

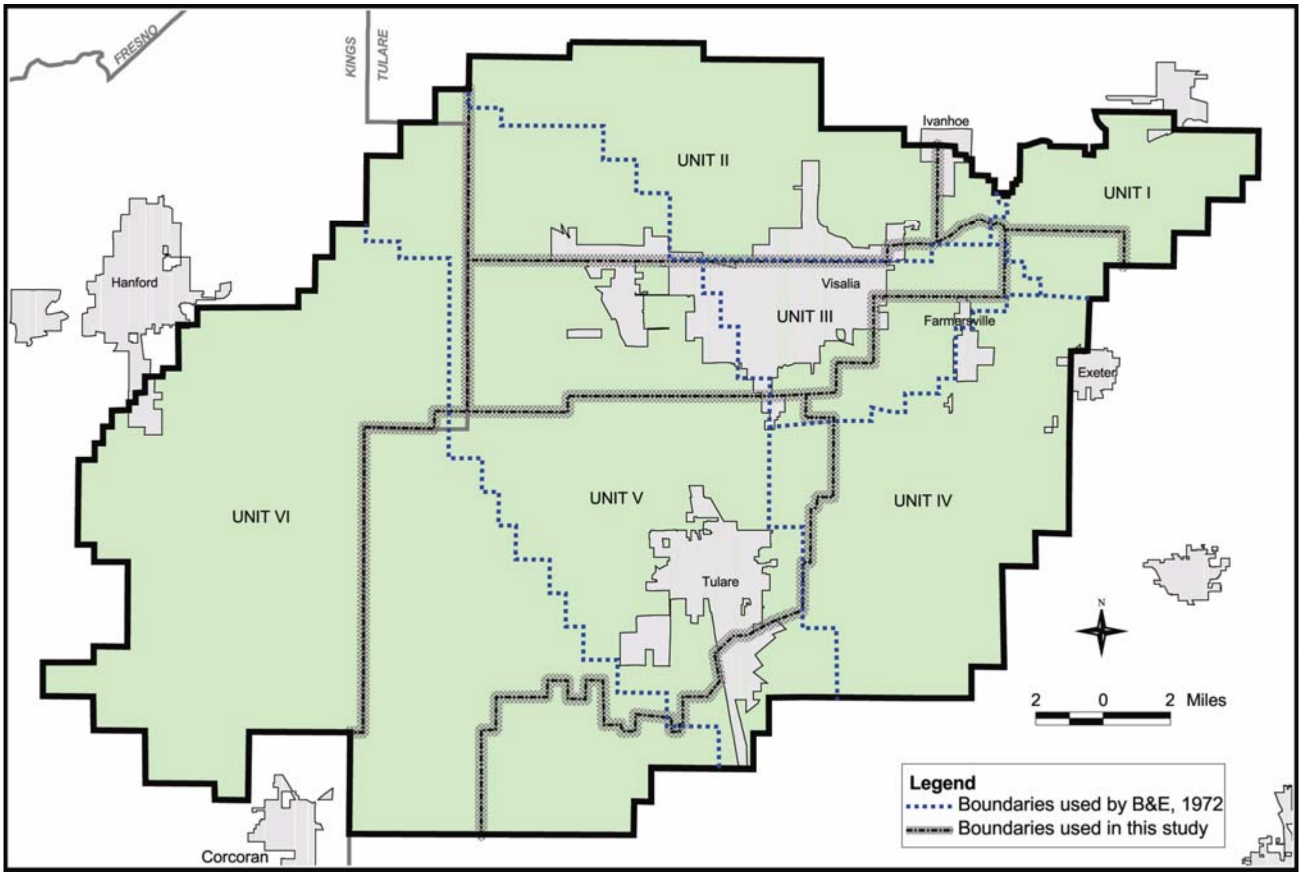

Figure 1. Kaweah Hydrologic Unit Boundary Changes

1.3.2 Modified Boundaries

A discussion of the basis for delineation of the six hydrologic unit boundaries used in this study is provided below. The boundaries, for the most part, are coincident with the service areas of the entitlement holders, a summary of which is provided on Table 2 - Hydrologic Unit Entitlement Holders, and shown graphically on Plate 3 - Entitlement Holder Service Area Map. The total acreage shown in Table 2, 356,214 acres, is greater than the actual District area, some 340,000 acres, due to overlap of entitlement holder areas.

Table 2. Hydrologic Unit Entitlement Holders

Hydrologic Unit No.	Service Area Data	
	Entitlement Holder	**Area (acres)**
I (Eastern)	Exeter Irrigation District	565
	Hamilton Ditch Canal	348
	Ivanhoe Irrigation District	190
	Lindsay-Strathmore Irrigation District	1,043
	Longs Canal Area	948
	Sweeney Ditch Area	509
	Tulare Irrigation Company	371
	Unincorporated	11,430
	Wutchumna Water Company	930
	Unit I Total:	16,334
II (St. Johns)	Alta Irrigation District	2,045
	Goshen Ditch Canal	5,553
	Mathews Ditch Canal	1,824
	Modoc Ditch Canal	6,245
	St. Johns Water District	13,300
	Unincorporated	27,025
	Uphill Ditch Canal	1,812
	Wutchumna Water Company	319
	Unit II Total:	58,123
III (Visalia)	Evans Ditch Canal	3,975
	Fleming Ditch Canal	1,635
	Modoc Ditch Canal	214
	Oakes Ditch Canal	790
	Persian Ditch Canal	6,237
	Tulare Irrigation Company	4,447
	Unincorporated	19,177
	Watson Ditch Canal	3,308
	Unit III Total:	39,783
IV (Outside Creek)	Consolidated Peoples Ditch Canal	15,635
	Elk Bayou Ditch Canal	7,467
	Exeter Irrigation District	800
	Farmers Ditch Canal	12,329
	Lindsay-Strathmore Irrigation District	111
	Oakes Ditch Canal	309
	Tulare Irrigation District	420
	Tulare Irrigation Company	1,529
	Unincorporated	36,004
	Unit IV Total:	74,604
V (Tulare)	El Bayou Ditch Canal	1,825
	Evans Ditch Canal	377
	Tulare Irrigation District	69,732
	Tulare Irrigation Company	1,527
	Unincorporated	10,953
	Unit V Total:	84,414
VI (Western)	Alta Irrigation District	510
	Corcoran Irrigation District	10,220
	Kings County Water District	24,821
	Lakeside Irrigation Water District	32,147
	Melga Water District	3,298
	Salyer Water District	3,678
	Unincorporated	8,782
	Unit VI Total:	83,456
	Total Acres	**356,714**

1.3.2.1 Hydrologic Unit No. I

Hydrologic Unit No. I, or the eastern area, includes the extreme easterly portion of the District and covers approximately 17,800 acres, or 5 percent of the District. Lands in this unit obtain groundwater exclusively from the shallow, unconfined alluvial deposits that are directly underlain by non-water-bearing granitic basement rocks. The westerly boundary of this unit was taken as the Rocky Hill fault, which establishes the easterly limit of water-bearing continental deposits. All surface runoff in the Kaweah River and deliveries of CVP water flow though this unit, either in the St. Johns River, the Lower Kaweah River, their tributaries, or in canal conveyance systems. For the most part, this unit is characterized by gaming reserves and canals with minimal conveyance losses in most years. Entitlement holders in this unit include Longs Canal, Hamilton Ditch Company, Lindsey-Strathmore Irrigation District, Sweeney Ditch area, and portions of the Tulare Irrigation Company and Ivanhoe Irrigation District. Much of the unit is unincorporated with respect to entitlements (refer to Table 2 and Plate 3).

1.3.2.2 Hydrologic Unit No. II

Hydrologic Unit No. II, the St. Johns area, is the northerly of three units (II, III, and IV), which obtain groundwater from the same deposits, namely, unconfined alluvium that extends westerly from Hydrologic Unit No. I and semiconfined continental deposits beneath the alluvium. The easterly boundary of these units is the Rocky Hill fault. The westerly boundary of this unit is somewhat coincident with the easterly edge of the Corcoran Clay. Hydrologic Unit No. II covers about 49,500 acres, or about 15 percent of the District.

The boundaries between Units Nos. II and III were selected based on the pattern of distribution of surface water. Surface water service within Unit No. II is almost exclusively from the St. Johns River system. As shown on Plate 3 and Table 2, entitlement holders in this unit include Mathews Ditch Company, Uphill Ditch Company, Goshen Ditch Company, St. Johns Water District, Modoc Ditch Company, and portions of Wutchumna Water Company. Alta Irrigation District in the extreme western part obtains surface water from Cottonwood Creek.

1.3.2.3 Hydrologic Unit No. III

Hydrologic Unit No. III, the Visalia area, is bounded on the east and west by the geologic features described for Hydrologic Unit No. II. Hydrologic Unit No. III covers some 35,500 acres, or about 10 percent of the District. The northerly boundary constitutes, for the most part, the southerly limits of service of the St. Johns system. The southerly boundary marks the approximate northerly limits of service from Consolidated Peoples Ditch to the east. Farther west in this unit, the TID Main Intake Canal, Cameron Creek, Packwood Creek, and Lower Kaweah River, all provide conveyance of surface water, and provide substantial recharge to the groundwater system. Entitlement holders in this unit include the Persian Ditch Company, Watson Ditch Company, Evans Ditch Company, Oakes Ditch Company, and Fleming Ditch Company.

1.3.2.4 Hydrologic Unit No. IV

Hydrologic Unit No. IV, the Outside Creek area, is the southeastern of the three units where groundwater is obtained from unconfined alluvium and the semiconfined continental deposits. These deposits are replenished largely from losses in Deep Creek, Farmers Ditch, Consolidated Peoples Ditch, and Outside Creek. Hydrologic Unit No. IV covers some 74,000 acres, or about 22 percent of the District. Entitlement holders in this unit consist of Elk Bayou Ditch Company, Consolidated Peoples Ditch Company, Farmers Ditch Company, and portions of Exeter Irrigation District and Tulare Irrigation Company.

1.3.2.5 Hydrologic Unit No. V

Hydrologic Unit No. V, the Tulare area, extends through the middle of the District on both sides of U.S. Highway 99 and is bounded on the east by the approximate edge of the Corcoran Clay. The westerly boundary was taken by B&E as the easterly limit of confining clays that overlie the Corcoran Clay (the A through D members that began to appear at the western edge of the District). Usable groundwater in the unit occurs both above and below the Corcoran Clay, and many water wells in this hydrologic unit perforate zones both above and below the E Clay, particularly in the easterly portion. Wells that perforate aquifers above and below the E Clay allow significant amounts of interaquifer flow, thereby equalizing piezometric (head) differences.

All of the service area of the TID is located in Hydrologic V, as well as a small, overlapping portion of the Elk Bayou Ditch Company. Hydrologic Unit No. V covers some 81,500 acres, or about 24 percent of the District (refer to Table 2 and Plate 3).

1.3.2.6 Hydrologic Unit No. VI

Hydrologic Unit No. VI, the western area, overlies a complex aquifer system where groundwater is found in interbedded lake and younger continental deposits above the E Clay in various degrees of confinement. Below the E Clay, groundwater in the interbedded lake and continental deposits, historically exhibited a high degree of confinement, a condition that may no longer be as pronounced.

Unlike Hydrologic Unit Nos. I through V where stream percolation can directly replenish the unconfined aquifers, percolation and irrigation return flow in Hydrologic Unit No. VI contributes only to shallow deposits that contain limited storage capacity. Within Hydrologic Unit No. VI are the service areas of Lakeside Irrigation Water District and portions of Corcoran Irrigation District, Melga Water District, Salyer Water District, and Kings County Water District. Hydrologic Unit No. VI covers some 83,000 acres, or about 24 percent of the District.

1.4 BASIC DATA

1.4.1 Data Management and Format

The initial efforts of the study concentrated on the collection, compilation, and review of available data. The kinds of data collected and evaluated included:

- Water well completion reports
- Oil well logs
- Water level data
- Precipitation records
- Water quality data
- Stream flow records
- Agricultural water demand
- Irrigated water data
- Artificial recharge data
- Municipal, community, rural and small water system demand data
- Wastewater data

Much of the data listed above were available and compiled in electronic tabular form. These electronic data sets were collected from various sources, including: DWR, National Oceanic and Atmospheric Administration (NOAA), Department of Conservation Division of Oil and Gas and Geothermal Research (DOGGR), Environmental Protection Agency (EPA), and the United States Geological Survey (USGS). Generally speaking, groundwater level data obtained from the DWR was in Microsoft (MS) Access database formats, whereas most sources of data, such as stream flow, precipitation, and California Irrigation Management Information System (CIMIS) evapotranspiration data, were compiled in MS Excel format. To the extent possible, all data collected for the study was compiled into MS Access database format. Existing Access databases were updated and expanded as new data was collected.

To assist in the management of the types of data listed above, Fugro staff compiled geospatial data from numerous sources for inclusion in a consolidated GIS database. All geographic data were re-projected as necessary to a common system. The coordinate system chosen for this project was Stateplane, California Zone IV, NAD83, feet. This coordinate system facilitates a simplified exchange of data. Most data were converted from native formats (AutoCAD, Excel, text, coverage) to ArcView shape files. Table 3 - Summary of GIS Data, presents the data that was placed in the consolidated database for production of maps and other products throughout the investigation.

Table 3. Summary of GIS Data

Theme	Source	Scale
County Boundary	USGS	1:100,000
Land Use*	CA DWR	1:24,000
District Boundary	KDWCD	Unknown
Urban Areas	TIGER	Varies
Roads	TIGER	Varies
Water Features (arc)	USGS	1:100,000
Water Features (poly)	USGS	1:100,000
Soils (STATSGO)	NRCS	1:250,000
Soil Survey Geographic database (SSURGO)	NRCS.	1:24,000
Precipitation	USGS et al.	1:1,000,000
Precipitation Stations	Fugro	1:1,000,000
Well Sites	CA DWR	Unknown
Wildcat Sites	Fugro	Unknown
Aerial Imagery	CA DWR/Fugro	N/A
Groundwater Basins	CA DWR	1:250,000
Cal Water Watersheds	CA DWR	1:24,000
Hydrologic Units	Fugro	1:220,000
Public Land Survey (sec)	CA DWR	1:100,000
Public Land Survey (t/r)	Fugro	1:100,000
Elevation	USGS/Fugro	1:24,000
Topographic Map	USGS	1:100,000
Topographic Map	USGS	1:250,000
Bovine Operations	Tulare County	Unknown
Poultry Operations	Tulare County	Unknown
Goat Operations	Tulare County	Unknown
Swine Operations	Tulare County	Unknown
Dairy Operations	Tulare County	Unknown
Dairy Operations †	Kings County	N/A

* Land use data available by county for several years
† Kings County dairy data in image format
TIGER: United States Census Bureau TIGER file
NRCS: Natural Resources Conservation Service

The locations of precipitation stations and associated data were acquired by Fugro and converted to GIS data. The locations were provided in tabular form by the NOAA. Additional precipitation data were compiled as GIS data by the USGS and distributed by the California Geospatial Information Library. The USGS data presents average precipitation from 1900 to 1960 derived from approximately 800 stations and is a combination of information collected by the USGS, DWR, the California Division of Mines and Geology (CDMG), and the National Weather Service. The minimum mapping unit was approximately 1,000 acres.

The EPA water quality data contain positional information that allows easy conversion to a GIS-compatible format. Spatial accuracy of the data varies widely, some are identified only by township, range and section, while others are located by survey or GPS. Water quality parameters can be interpolated between sample locations and compared spatially and temporally.

For land use classification, acreage data of crop types and individual crops was compiled from DWR files in GIS format. These data are highly detailed and available for Tulare County (1993 and 1999) and for Kings County (1991 and 1996).

These land use data were further expanded by compiling and digitizing land use data for Kings County from the end of the 1980s to merge with Tulare County data digitized by Zheng (undated).

1.4.2 Water Well Completion Reports

Water well drilling contractors in California are required to submit Completion Reports of all wells to the DWR. The DWR Water Well Completion Reports were used in this study to delineate and correlate aquifers and aquitards in the District and in the preparation of hydrogeologic cross sections. The well completion reports are stored and maintained at the DWR-Fresno District, as well as at the District (well completion reports prior to about 1970), and at the County of Tulare Environmental Health Division. Completion reports are filed at the Division of Environmental Health according to the Permit Number. Until the mid 1990s, copies of the reports were forwarded on to the DWR and filed according to location by township and range.

Well completion reports on file with the DWR were reviewed and collected in their entirety for all sections within the boundaries of the District (refer to Table 4 - Summary of DWR Well Completion Reports). These well completion reports almost exclusively date from about 1970 to 2000. B&E, as part of the 1972 investigation of the District, similarly collected all available well completion reports on file with the DWR up to about 1970. The combined well completion reports, some 7,000 in number, were subsequently reviewed, compiled, and sorted for geologic data, well design, water level, and aquifer parameter data. Plate 7 - Distribution of Water Well Data Sets, provides a representation of the distribution of well log data in the District by township and range for the post-1970 DWR file data. Geophysical electric log data and well pump test data were also obtained for about 100 water wells in the District.

Table 4. Summary of DWR Well Completion Reports

Hydrologic Unit	Township/Range	Sections	Approximate Number of Well Completion Reports	Approximate Number of Geophysical Logs
I	T17S/R26E	35-36	50	--
	T18S/R26E	1-5, 8-24, 27-29	* 450	5
	T18S/R27E	4-9, 18	70	1
II	T17S/R23E	25-27, 34	* 7	0
	T17S/R24E	19-22, 25-36	70	--
	T17S/R25E	30-31	70	--
	T18S/R24E	1-5, 9-15, 19-22	290	4
	T18S/R25E	1-24	* 700	3
	T18S/R26E	7, 18-19	* 450	5
III	T18S/R24E	25-26, 35-36	* 290	4
	T18S/R25E	23-36	* 700	3
	T18S/R26E	19, 29-31	* 450	5
	T19S/R24E	1, 12	* 240	1
	T19S/R25E	1-12, 15-18	* 375	2
IV	T18S/R26E	31-34	* 450	5
	T19S/R25E	1, 12-15, 19-36	* 375	2
	T19S/R26E	4-9, 16-21, 28-33	250	1
	T20S/R25E	1-5, 8-17, 21-28	*250	1
	T20S/R26E	5-7, 18-19	25	0
V	T17S/R23E	33-34	* 7	0
	T18S/R23E	1-28, 33-36	* 260	5
	T18S/R24E	6-8, 16-21, 27-35	* 290	4
	T19S/R23E	1-4, 9-16, 21-27, 35-36	* 150	2
	T19S/R24E	2-36	* 240	1
	T20S/R23E	1-2, 12	* 150	2
	T20S/R24E	1-29, 34-36	* 225	2
	T20S/R25E	6-7, 18-20, 29-30	*250	1
	T18S/R24E	1	* 100	0
VI	T18S/R22E	24-26, 32-36	Not Available from DWR Files	
	T18S/R23E	19, 28-33	* 260	5
	T19S/R21E	1, 12-13, 22-27, 34-36	90	0
	T19S/R22E	1-36	290	4
	T19S/R23E	4-9, 16-21, 27-34	* 150	2
	T20S/R21E	1-3, 12-13, 21-28, 35-36	70	6
	T20S/R22E	1-36	175	10
	T20S/R23E	2-36	* 150	2
	T20S/R24E	19, 29-33	* 225	2
	T21S/R22E	4-9	Not Available from DWR Files	
	T21S/R23E	1-13	100	1
	T21S/R24E	2-9, 16-18	* 100	0

Notes: * In some cases, townships include multiple hydrologic units
Geophysical logs from approx. 40 additional Division of Oil & Gas wells are located throughout the District.
Table is only for logs obtained from the DWR Fresno office that date from about 1970 to 2000.

1.4.3 Oil and Gas Well Log Data

Records of exploratory oil wells are maintained at the Division 4 and 5 offices of the DOGGR. As is the case for all data sources, available data sources were identified and copied as appropriate. Available records included geophysical and formation logs, compensated acoustic velocity logs, dipmeter logs, mud logs, core records, and well driller's reports for individual wells identified. These logs are kept in a variety of formats including hardcopy, microfilm, and microfiche.

Approximately 47 wildcat wells were identified by a review of Regional Wildcat Maps maintained by the DOGGR that were relevant to the WRI (refer to Plate 8 - Wildcat Borehole/Well Location Map). Table 5 - Summary of Typical Wildcat Oil Well Data Sets presents a summary of typical data for wildcat wells identified in the study area as well as the type(s) of data available from the DOGGR for these wells. In that the subject WRI is a hydrogeologic study, the oil and gas well-log data review was focused on shallow (i.e., <2,000 feet) data, and to define the base of permeable sediments and fresh groundwater.

The District area is not known as a major oil-producing region of California, and the number of wildcat wells drilled and producing oil and gas wells is very limited. The data indicate that for the wells identified, however, a relatively diverse set of data are available. The geophysical logs available include spontaneous potential, electric resistivity, and various other parameters of geologic units. Formation logs include descriptions of drilled cuttings and/or cores.

1.4.4 Water Level Data

Water level data throughout the State of California are stored and maintained in a database by DWR, Division of Planning and Local Assistance. The database, obtained from the Internet, provided predominantly spring and fall water level readings from 1920 to present along with latitude and longitude to be used for plotting well locations. The District maintains limited water level data for wells that are distributed geographically throughout the District. Water level data have been used by DWR staff to generate annual groundwater elevation contour maps for the "unconfined aquifer" for the Spring period. These maps are available to the public and are used by DWR staff for groundwater storage calculations and for comparative purposes related to their 5-year statewide water supply reports. DWR staff have not calculated storage changes (annually or otherwise) based on the water level data. The data are also used to generate groundwater elevation hydrographs and as appropriate, annual groundwater elevation contour maps for the "pressure aquifier system." Preparation of these latter maps were discontinued by the DWR in 1989.

The DWR maintains water level data for nearly 20,000 wells in California, of which 995 lie within the Kaweah Basin. The District is fully contained by the Kaweah Basin (DWR Unit I232), which is a subset of the larger San Joaquin Valley Hydrologic Region. Data for the wells within the Kaweah Basin span from 1920 to present. A total of 556 of the wells in the DWR database are within the specific District boundaries. Additionally, District paper and electronic files contain water level readings from 168 wells within the District on fall/spring schedule from 1965 to present.

Table 5. Summary of Typical Wildcat Oil Well Data Sets

Borehole/Well I.D.* (State No.)	Borehole/Well/Location (Township/Range/Section)	Well Status	Total Borehole/ Well Depth (feet BGS)	Type of Data Available (see notes)	Depth Interval (feet BGS)	Key to Well Location Map**
ARCO Oil & Gas Co. "Churchill" 1 42-5566	T20S - R24E - Section 35 107-00218	abd	5,566'	SP	400'-5,560'	No. 1
Tannerhill Oil Co. "Brazil" 27X 78-3450	T20S - R25E - Section 9 107-20104	abd	3,450'	DIL mud	350'-3,450' 350'-3,450'	No. 2
Freeport Oil Co. "Soults" 1 76-6375	T20S - R24E - Section 8 107-20074	abd	6,375'	DIL	90'-6,380'	No. 3
ARCO Oil & Gas Co. "North Tulare Comm." 1 42-5356	T19S - R24E - Section 33 107-00211	abd	5,356'	SP	410'-5,355'	No. 4
Tulare Oil Co. 1 22-3247	T20S - R24E - Section 1 107-00217	abd	3,247'	None	--	No. 5
Tannerhill Oil Co. "Cardosa" 16X 78-3866	T19S - R25E - Section 31 107-20117	abd	3,866'	DIL CAV	426'-3,862' 426'-3,862'	No. 6
Tannerhill Oil Co. "Warren" 17 78-3495	T19S - R25E - Section 29 107-20105	abd	3,495'	DIL CAV mud, SWS	377'-3,496' 377'-3,496' 377'-3,496'	No. 7

Notes:

* - Well Owner / "Lessee and/or Well Name" / 80 (year drilled) - 3486 (total depth)
** - See Plate 8 - Wildcat Borehole/Well Locations
T.R.S. - Township, Range, and Section
feet bgs - Feet Below Ground Surface
GL - Gamma Ray Log
EL - Electric Log
CL - Caliper Log
WDR - Well Driller's Report
WQD - Water Quality Data
PD - Production Data
CR - Casing Record
abd - Abandoned
-- - Not Available or Not Applicable
SP - Spontaneous Potential Log (electric log)
FDC/CDLC - Formation Density Logs
SWS/Core - Sidewall Samples/Core Record
mud - Mud Log
DIP - Dipmeter Log
DR - Driller's Log
DIL - Dual Induction Log
CAV - Compensated Acoustic Velocity Log
Lithology - Sand Description
Most wells in District 4 (Bakersfield) (identified by included API numbers) contain a Well Driller's Report and all contain a casing record.
Production data are available for all wells on the Division's web site.

DWR water level readings include latitude and longitude, state well number, date of reading, depth to water and water surface elevation in feet above mean sea level. District water level readings include state well number and spring and fall depth to water data. Other sources of data include water purveyors (municipal, County Service Areas, and private), water system files from Environmental Health, and regulated discharge site files from the Regional Water Quality Control Board.

Both the DWR and District network of observation wells in the study area are geographically dispersed in a manner that is excellent to determine groundwater movement across the District, identify pumping depressions, and to calculate annual changes of groundwater in storage. It is unclear, however, as to how wells included in the DWR network were qualified for inclusion in the data collection program. As part of the WRI, each well for which water level data are available was reviewed with respect to depth, perforated interval, aquifer represented (confined or unconfined), and data reliability.

Water level maps were digitally reconstructed for each year of the base period to determine annual change of groundwater in storage, and for each hydrologic unit. DWR well completion reports were used to generate a contour map of specific yield values for aquifers within the range of base period water level fluctuation. The results of this analysis are presented in Chapter 3 of this report.

1.4.5 Precipitation Data

Precipitation data were obtained from the National Climatic Data Center, which is a part of the NOAA. Precipitation data are an important component of the hydrologic budget, and were used in combination with other data (evapotranspiration, runoff/streamflow) to estimate agricultural water demand, and to establish a base period.

Precipitation data obtained from NOAA contained data for precipitation stations located in the counties of Tulare and Kings surrounding District boundaries. Records for nine stations were obtained. The database contains monthly totals for each of the precipitation stations. The period of record for the precipitation stations ranges greatly. For example, the station at Visalia (Station No. 49367) has an essentially continuous period of record beginning in 1878 (120+ years). Most other stations selected, however, have a continuous period of record from the 1930s and 1940s to present. Data from a single selected station, Lodgepole (Station No. 45026), begins in 1970 and continues to present. Most of the other stations have been discontinued.

NOAA data are available from 17 stations in Tulare County and 6 stations in Kings County with monthly precipitation data. The periods of record of these stations began between the 1930s and 1960s. Of the 23 stations, 12 have been discontinued and/or data are unavailable after 1987. For this study, it is important to use precipitation data that is as consistent as possible with the period of record available for data of the other components of the study (e.g., demand data, water level data, etc.). For example, data for a precipitation station with 30 years of record that ends in 1951 is of little value, when the WRI base period begins in the early 1980s.

The remaining 11 stations are currently active. As an initial screening, stations with at least 30 years of record are considered significant. Less than 30 years of record is considered insufficient to identify the significant variations in cycles of drought and wet periods.

Presented in Table 6 - Key Precipitation Recording Stations, are those stations in the study area that have a period of record of a minimum 30 years and are currently active. The station locations are shown on Plate 9 - Precipitation Station Location Map.

Table 6. Key Precipitation Recording Stations

Station No.	Station Name	Township/Range/ Section	Year Record Began	End of Record	Years of Record	Elevation (feet, MSL)
43747	Hanford 1 S	T18S/R21E-S31	1932	2001	69	74.7
42012	Corcoran Irrig. Dist.	T21S/R22E-S15	1946	2001	55	61
49367	Visalia	T18S/R25E-S30	1878	2001	123	99.1
44957	Lindsay	T20S/R27E-S9	1932	2001	69	128
44890	Lemon Cove	T18S/R27E-S3	1932	2001	69	156.4
47077	Porterville	T21S/R27E-S25	1932	2001	69	119.8
48917	Three Rivers Edison PH 1	T17S/R29E-S8	1949	2001	52	347.5
40343	Ash Mountain	T17S/R29E-S32	1932	2001	69	1707.6
45026	Lodgepole	T15S/R30E-S21	1970	2001	31	2052.8

As shown, there are nine stations in and surrounding the study area with significant periods of record. The stations are distributed widely over the study area. Two stations with an adequate period of record, Grant Grove in Tulare County and Kettleman Station in Kings County, were omitted because of distance from the study area.

Review of Table 8 and Plate 9 reveals few deficiencies in the currently compiled data. Although only a single precipitation station, Visalia, is within the boundaries of the District, the remaining precipitation stations are sufficiently geographically dispersed to evaluate precipitation patterns, spatially and temporally, over the District.

1.4.6 Surface Water Data

Surface waters impacting the District that are generated on a local basis include the Kaweah River, Dry Creek, Cottonwood Creek, Mehrten Creek, Yokohl Creek, and Lewis Creek. Sources of data for each of these rivers and creeks include the Kaweah and St. Johns Rivers Association, the Consolidated Peoples Ditch Company, and the USGS.

The Kaweah and St. Johns Rivers Association accumulates data on a daily basis for the Kaweah River, Dry Creek, and Yokohl Creek. This information is tabulated on a daily basis and for the last several years has been tabulated on a computer-driven database. Annual reports are published by the Association, which are currently in the process of being brought current.

Even though the annual reports are not in a current state, the database of the Association is current and is available for purposes of future task that are required as part of this WRI.

The records of the stream groups impacting the facilities and stockholders of the Consolidated Peoples Ditch Company and the other companies that they manage are in a hit and miss fashion. Substantial data gaps exist; however, in the overall analysis, the data gaps represent relatively small quantities of contributory flows and their absence should not be of significant impact.

The records of the USGS are, for the most part, supplemental to the records of the Association and the Consolidated Peoples Ditch Company. The information that is published by the USGS, however, does fill some of the data gaps that exist in the information related to the local stream groups.

1.4.7 Imported Water Data

Supplemental sources of water supply have been imported to the District since its inception. Deliveries to lands that eventually became a part of the District started in the late 1800s and were made available from the Kings River. An additional source of supplemental supply was made available to lands located within the District in the early 1950s. The source of these supplies was from the CVP and took the form of both long-term contract supplies and short-term contract supplies. With the advent of the termination of short-term contracting procedures, supplemental supplies, in addition to the long-term CVP supplies, have been made available through the vehicle of temporary contracts.

Groundwater within the District is also impacted by the delivery of water to lands within the service area of the State Water Project (SWP). Exchanges between Kings River supplies and SWP supplies have further augmented the impact of the construction of the SWP.

Supplies made available from the Kings River impact the north, northwestern, and westerly areas of the District. Information as to the gross deliveries made available to these areas are available from the Kings River Water Association. The watermaster of the Kings River Water Association publishes an annual report that contains the information necessary to document the gross delivery information. Specific information related to deliveries into areas in and adjacent to the District on the north, northwest, and westerly boundaries are available from records of the Alta Irrigation District, the Corcoran Irrigation Company, the Corcoran Irrigation District, the Kings County Water District, the Lakeside Irrigation Water District, and the Melga Water District.

Deliveries of CVP supplies into areas in and surrounding the District are summarized in annual reports published by the U.S. Bureau of Reclamation. Principal deliveries of CVP water into the District have been related to the short-term contract previously held by the District and the long-term CVP contract held by the TID. The records of the U.S. Bureau of Reclamation document the specific deliveries into the District and into the TID, and parallel documenting records are available from each entity. The pricing structure of CVP supplies has and is further anticipated to impact deliveries into the TID. Studies indicating the decline of the average annual deliveries from the historic 108,000 af to a potential low-average of 60,000 af are available in the public domain.

The District is impacted by CVP deliveries to districts surrounding the District, as well as to the City of Visalia. Records of these deliveries are available from the U.S. Bureau of Reclamation on a gross annual diversion basis with specific information available to document deliveries to specific lands that overlap the boundaries of the CVP contracting entities with the boundaries of the District and adjacent thereto. These contracting districts include the Exeter Irrigation District, the Ivanhoe Irrigation District, the Lewis Creek Water District, the Lindmore Irrigation District, the Lindsay-Strathmore Irrigation District, and the Lower Tule River Irrigation District.

SWP delivery information is available on a gross basis from the DWR. Specific delivery information to lands adjacent to the District is available from the Tulare Lake Basin Water Storage District. Through cooperation with entities in and adjacent to the District, information related to historic transfers are likewise available.

Records exist with the District and with the U.S. Bureau of Reclamation relative to contract and temporary purchases of supplemental surface water by the District and by non-CVP entities located within the District. On a like data available basis, the description of the exchange programs of the City of Visalia and the quantities delivered under those exchange programs are available.

1.4.8 Water Quality Data

State and local agencies were contacted to evaluate the availability of surface and groundwater quality data for the study area. Agencies contacted included the Regional Water Quality Control Board-Central Valley Region (RWQCB), Kings County Health Department (KHD), Tulare County Environmental Health Department (TEHD), California Water Services Company (Cal Water), Tulare County Resources Management Agency-Solid Waste Division (TRMA), City of Visalia Public Works Department (VPWD), and the DWR.

Additionally, water quality data are stored electronically by the United States Environmental Protection Agency (EPA) Office of Drinking Water. The EPA maintains two water quality data management systems: the STORET Legacy Data Center, and the Modernized STORET. The Legacy Data Center (LDC) contains historical water quality data dating to the early 1900s and collected up to the end of 1998. Modernized STORET contains data collected beginning in 1999, along with older data that had been documented and transferred from the LDC. Both systems contain biological, chemical, and physical data on surface water and groundwater. The water quality data may be sorted and retrieved by date, location, or by parameter.

As presented above, the Tulare County Resources Management Agency-Solid Waste Division, Kings County Health Department, DWR, Cal Water, RWQCB, and U.S. EPA appear to be the primary sources of groundwater quality data within the study area. The data sources identified that a relatively broad set of data was available for the study area and overall these data are representative of the study area. The potentially limiting factor in the water quality data is the consistency of the data in terms of future activities such as preparation of long-term chemical hydrographs to assess trends in water quality. More specifically, the currently available data limited the success of future District-wide graphing or other illustrations through the lack of similar data across the study area from east to west and/or north to south.

1.4.9 Artificial Recharge

The District has for many decades operated groundwater recharge basins for purposes of augmenting water supply within the District. Information on the history of development, operation, size, location, approximate diversions, maintenance, and other features of each recharge basin are available from the District in various forms.

A summary of the characteristics of each recharge basin has been prepared and is provided later in this report in Chapter 4. A map of the location of each recharge basin is provided on Plate 10 - Recharge Basin Location Map.

The District presently operates about 40 recharge basins with a combined area of about 2,100 acres. B&E (1972, pg. VI-16) provided a brief summary of District recharge activities as of about 1970. At that time, there were about 36 spreading basins both in and immediately adjacent the District covering some 4,600 acres, with an estimated recharge capacity of 1,100 af per day. Total annual average recharge to the District by such activities was not directly provided by B&E.

Recharge basins in the District serve to supplement natural replacement to the groundwater reservoir. Although the source of supply to each recharge basin is variable from year to year, the approximate quantities of artificial recharge were tabulated for each year of the base period for each hydrologic unit. Tabulation and accounting of inflows depends on the accuracy of data relating to the number of days per year of wetted area in each basin and the hydraulic conductivity or percolation capacity of the basin, typically expressed in units of gallons per day per square foot. These calculations and tabulations are presented in Chapter 4 of this report.

1.4.10 Agricultural Water Demand

An important factor in the development of the hydrologic budget for the District is an understanding of consumptive use versus irrigation application. Consumptive use (water lost to the hydrologic system) is usually different than the required irrigation application. Estimating actual consumptive use involves identification of the types of irrigation inefficiencies and the destinations of both the losses due to irrigation inefficiencies and conveyance.

A complicating factor in the WRI is the use of both surface and groundwater supplies to meet irrigation requirements. Surface water supplies are delivered through public and private irrigation district canals and ditches, many of which are earthen and subject to significant conveyance losses. To reduce the complication, conveyance losses in the public/private agency systems were estimated separately from on-farm conveyance losses. These conveyance losses were identified and quantified in the analysis of surface water deliveries in

Chapter 4. On-farm conveyance losses were treated as part of the overall computation of on-farm irrigation efficiency.

Data used to estimate the agricultural water demands in the District for each year of the base period included land use clarification maps, net annual water use estimates for the major crops, effective preparation, leaching factors, irrigation efficiency, and weather data. Most of these data were readily available in the public domain and readily applied to the WRI.

1.4.11 Municipal and Community Water Demand

Water demand for municipal and community water systems in the District is available directly from the cities of Tulare, Farmersville, and Exeter, Ivanhoe Public Utility District, and the California Water Service Company (Cal Water), which services the City of Visalia. Although the City of Exeter and the community of Ivanhoe lie partially within the District, demand data for their entire systems are available and were obtained for the base period. Data pertaining to small community water systems within the District were obtained from the Tulare and Kings County Environmental Health Departments.

Virtually all municipal and community consumptive water demand within the District is met through groundwater pumping; thus, the groundwater production data obtained from each purveyor was a critical component of the hydrologic budget. Monthly production records were obtained directly from each of the municipal water systems; however, the duration of recorded production data varied with each water system. The most extensive period of record obtained was that of the City of Farmersville, which extended back to 1957.

Each of the five municipal water systems listed above are supplied by their own water wells that are located predominantly within the service limits of each respective system. As previously mentioned, the City of Exeter and the Ivanhoe Public Utility District lie partially within the District.

1.4.12 Rural Water Demand

Rural water demand is the water used by small to large animal farms and residential dwellings in unincorporated parts of the District that are not served by municipal or small community water systems. This includes dairies and the non-agricultural ranchette properties scattered throughout the District.

There was no organized or centralized means of obtaining data for rural domestic water use within the District. Information pertaining to the location and size of dairies within the District was made available by the Tulare County Environmental Health Department. The most recent source of information for rural water use by dairies was obtained from studies completed by the University of California Cooperative Extension Agriculture and Natural Resources Department. The studies have assessed water usage and demand on numerous dairies throughout the central valley and place a water duty factor on a per-cow basis.

A significant portion of the rural domestic water demand is expected to be from the animal farms and dairies located throughout the District. The County databases show that there are approximately 150 dairies and other animal farms within the District that vary in size and acreage. Plate 11 - Location of Dairies, presents the locations of the 150 dairies located within the District. Calculating water demand for these facilities was accomplished by assessing a water duty factor for each facility based on usage per animal, and for facility operators (i.e., washdown water).

Calculation of water demand for the remaining rural domestic needs were based on population estimates and the number of dwelling units within the District. The number of dwelling units for each hydrologic unit was then multiplied by a water duty factor, which accounts for typical interior household use as well as a widely variable exterior water need.

1.4.13 Data Summary

The collection, compilation, and review of available data for conducting the WRI are summarized in Table 7 - Summary of Data.

1.5 HYDROLOGIC BASE PERIOD

1.5.1 Hydrologic Base Period Definition

The purpose of a hydrologic base period is to define a specific time over which elements of recharge and discharge in a groundwater basin may be compared. This period, when properly selected, allows investigators to discern long-term basin trends of supply and demand. Some of the analyses that require a hydrologic base period include:

- Water level trends
- Changes of groundwater in storage (both seasonal and long term)
- Estimates of the annual components of inflow and outflow to the zone of saturation.
- Safe yield estimates
- Groundwater modeling

Table 7. Summary of Data

Data	Data Availability, Quantity, and Quality
Water Well Completion Reports	Sufficient number of well logs (estimated to be in excess of 7,000) are available throughout the District and are believed to provide an excellent geographic distribution for all hydrologic units. Geophysical electric log data are considerably more abundant in Kings County where such surveys are required by well ordinance. The quality of the well completion reports range from excellent to poor. Overall, the data are adequate to characterize aquifer/aquitard systems, aquifer correlation, and well design.
Oil and Gas Well Logs	The information on oil and gas well logs adds to the well completion reports but is viewed as of minimal value due to a limited number of wildcat or production wells in the District (about 50) and geophysical electric log data that often does not include the upper 500 feet of the drill hole. Overall, the data are adequate.
Water Level Data	Water level data over the District and for the selected base period (both Spring and Fall data) is adequate. A concern exists that sufficient well design data can be keyed to each observation/monitoring well to determine single or multiple aquifer representation of the piezometric surface (i.e., above/below or combined water levels in the area of the Corcoran clay. Overall, the data are viewed as adequate.
Precipitation Records	Eight precipitation records in and adjacent the District exist, which provide long-term records to evaluate and select and appropriate base period and to estimate effective precipitation. Overall, the data are adequate.
Water Quality	General mineral analyses are available for several thousand wells in the District, although without detailed review it is difficult to assess the overall spatial distribution and continuity of records over time. In general, the available data appears adequate.
Artificial Recharge	The District maintains records on some 40 existing and planned artificial recharge basins from which annual estimates of recharge, by hydrologic unit, can be estimated. Overall, the data are adequate.
Imported Water	The District and other agencies maintain excellent records on the quantities of imported water that have been delivered within the District over the base period. Overall, the data are adequate.
Surface Water	The Kaweah and St. Johns Rivers Association, as well as other agencies, tabulate data for the major distributaries in the District. Although some gaps may exist, the data are adequate to develop the routing of surface water deliveries for each year of the base period and for each hydrologic unit.
Agricultural Water Demand	Data are available in the form of land use, CIMIS, irrigation efficiency, and related components to determine gross required pumping within the District over the base period. Overall, the data are adequate.
Municipal & Community Water Demand	Data from municipal pumps and small domestic water systems are either directly or indirectly available. The data are viewed as adequate.
Rural Domestic Water Demand	Rural non-agricultural water demand related to dairies and nurseries are available in the form of land use and agency studies. Data may be inadequate on the ruse of water from dairies on adjacent agricultural lands. Overall, the data are viewed as adequate
Wastewater	Data appear adequate to characterize the point sources of wastewater in the District, both from the standpoint of water quality and water re-use.
Water Well Pumping Tests	Data are generally available, but subject to release by Pacific Gas and Electric, or private well owners.

The base period analysis uses water years, which in Tulare and Kings Counties run from October 1 through September 30. For example, the 1981 rainfall year is October 1, 1980, through September 30, 1981. The rainfall years establish annual precipitation. The following quotation (similar to that contained in the 1972 B&E report) summarizes the main considerations for base period selection:

> "The base period should be representative of long-term hydrologic conditions, encompassing dry, wet, and average years of precipitation. It must be contained within the historical record and should include recent cultural conditions to assist in determining projected basin operations. To minimize the amount of water in transit in the zone of aeration, the beginning and end of the base period should be preceded by comparatively similar rainfall quantities" (DWR, 2000).

Other considerations for base period selection include data availability, surface water reservoir management, and the historical development of water supplies imported from outside the District. B&E (1972) also appropriately commented that the base period should be of relatively short duration. In their study, B&E was faced with the challenge of accounting for a significant change in water supply to the District in the early 1960s resulting from the construction of Terminus Reservoir. Accordingly, two base periods were selected by B&E (1972). A long-term period of 32 years extending from 1934 to 1965 was selected based on Kaweah River runoff data and the cyclical (although materially wetter) patterns of precipitation during this 32-year period. A shorter 5-year period from 1961 to 1966 was also used based on operation of Terminus Reservoir and its affect on the seasonal patterns of flow in the Kaweah River and the resulting changes in regulated surface water management in the District.

It should be noted that in the District, water supply is dominated by the availability of surface water, and the base period selection needs to consider the correlation of precipitation and runoff patterns. A useful comparison of runoff to precipitation within the Tule River watershed is provided by SMB-CE, Inc. (October 2001). The conclusion reached in this analysis of the 35-year period 1965 to 1999 was that a slight divergence of runoff to precipitation (i.e., less runoff than expected) occurred for the period 1988 to 1995. Such analysis was not performed as part of the base period selection for the WRI because (as is discussed below) the relation between runoff and precipitation for the base period selected (1981 to 1999) displays a relatively robust correlation.

1.5.2 Data Review

Precipitation records for about 15 stations in and adjacent the District were reviewed, eight of which are shown on Table 8 - Precipitation Stations Used for Base Period Analysis and Selection. Runoff records at the Three Rivers gauging station and at McKay Point were similarly reviewed and are shown on Table 9 - Runoff Stations Used for Base Period Analysis and Selection. Of the 15 precipitation stations, the eight stations were selected as best representing the historical record of precipitation in the area, based both on geographic distribution and period of record.

Table 8. Precipitation Stations Used for Base Period Analysis and Selection

Station No.	Station Name	Elevation (feet, MSL)	Township/ Range/ Section	Latitude	Longitude	Period of Record	Average for Period of Record (inches)	Range for Period of Record (inches)	Average Precipitation 1981 to 1999 (inches)
43747	Hanford 1 S	74.7	T18S/R21E-S31	36 19'	-119 38'	1932-Present	8.3	3.03 - 17.76	8.86
42012	Corcoran Irrig. Dist.	61	T21S/R22E-S15	36 06'	-119 35'	1946-Present	7.01	2.51 - 16.42	7.64
49367	Visalia	99.1	T18S/R25E-S30	36 2'	-119 18'	1878- Present	10.34	3.89 - 22.75	11.23
44957	Lindsay	128	T20S/R27E-S9	36 12'	-119 03'	1932-Present	12.08	5.05 - 26.47	12.68
44890	Lemon Cove	156.4	T18S/R27E-S3	36 23'	-119 02'	1932-Present	14.43	5.63 - 28.77	15.06
47077	Porterville	119.8	T21S/R27E-S25	36 04'	-119 01'	1932-Present	11.33	4.05 - 22.03	11.57
48917	Three Rivers Edison PH 1	347.5	T17S/R29E-S8	36 28'	-118 52'	1949-Present	22.81	6.52 - 51.88	26.17
45026	Lodgepole	2,052.8	T15S/R30E-S21	36 36'	-118 44'	1970-Present	44.69	14.84 - 84.47	46.11

Table 9. Runoff Stations Used for Base Period Analysis and Selection

Station No.	Station Name	Elev. (feet, MSL)	Township/ Range/ Section	Latitude	Longitude	Period of Record	Average for Period of Record	Range for Period of Record
NA	Kaweah River at Three Rivers + South Fork of Three Rivers	833	T17S/R28E-S13	36°26.636'N	118°54.263'W	1904-Present	431,200	93,000 - 1,402,000
NA	Dry Creek Near Lemoncove	589	T17S/R27E-S15	36°27.025'N	119°1.707'W	1962-Present	19,100	197 - 93,800
NA	Kaweah River Below McKay Point	455	T18S/R27E-S4	36°23.387'N	119°2.893'W	1962-Present	419,600	60,800 - 1,331,300

Graphs showing the cumulative departure from mean precipitation for the above eight stations were prepared and presented in the Task 1 Interim Report. The departure from mean precipitation is the difference between precipitation in a specific year and the mean precipitation value of the data set. The cumulative departure from mean graphs the sum of these departures over time, beginning with the first year departure and adding the departure for each subsequent year (cumulative). The cumulative departure value is identical at the beginning and ending year of a representative hydrologic base period.

The Visalia Station has the longest continuous period of record in the District and is appropriate to choose as the reference record (refer to Plate 4 - Cumulative Departure from Average Annual Precipitation at Visalia). A reference record is needed to establish a reference period over which the cumulative departures for all the stations are calculated. Without a reference period, there is no way to correlate cumulative departure data between stations.

Based on the cumulative departure from mean precipitation at this station, the most appropriate reference period begins with rainfall year 1974 and runs through 1999 (refer to Plate 5 - Kaweah River Runoff Versus Mean Precipitation at Three Rivers Station). The average for the reference period approximated the long-term average (within 5 percent).

Mean precipitation and cumulative departure from mean precipitation for the eight representative basin precipitation stations were prepared using data from rainfall years 1974 through 1999. Where precipitation data gaps existed in the historical record, estimates were used, using linear regression analysis on data between precipitation stations.

Plate 6 - Cumulative Departure from Average Annual Precipitation, Composite Data, shows a composite cumulative departure curve for the eight precipitation stations. The cumulative departure from mean precipitation for each year was calculated individually at each station, then averaged to derive the composite graph. The climatic trends present in the composite cumulative departure curve exhibit cyclic wet and dry periods. The composite curve obviously depicts average precipitation over the entire District from stations with vastly different annual precipitation, due to the pronounced orographic effects in the area (refer to B&E, 1972, Figure 3).

1.5.3 Hydrologic Base Period Selection

A review of the cumulative departure graphs for each of the eight stations identifies the rainfall year 1999 as the most recent year suitable for ending the hydrologic base period. Precipitation totals in prior years (particularly 1997) are generally too wet, which would result in water in transit through the unsaturated zone that would not be represented as a rise in water levels. The candidate years for beginning the base period include 1978, 1981, and 1987. A review of the differences in cumulative departure for these years is summarized in the following Table 10 - Base Period Analysis (1975-2000 Reference Period).

Table 10. Base Period Analysis (1975-2000 Reference Period)

Station Number	Station Name	Difference In Cumulative Departure Between Base Period Years (inches)		
		1978-1999	1981-1999	1987-1999
43747	Hanford	-8.50	-8.33	-8.14
42012	Corcoran	-9.21	-9.55	-9.07
49367	Visalia	-5.64	-5.96	-5.97
44957	Lindsay	-3.96	-4.51	-5.07
44890	Lemoncove	-1.62	-2.13	-2.79
47077	Porterville	-5.18	-5.62	-5.91
48917	Three Rivers Edison	9.26	8.98	6.16
45026	Lodgepole	31.19	28.93	23.11
Average Cumulative Departure:		0.85	0.23	-0.96

The most suitable candidates for the hydrologic base period were rainfall years 1978-1999 and 1981-1999. Considering the availability of data, especially land use and CIMIS data, the latter period of 1981-1999 is preferred. The relationship of surface water runoff to precipitation was also considered in the selection of the base period by plotting runoff at Three Rivers versus precipitation for various periods. For the most part, a robust coefficient of correlation was obtained, showing a strong linear relationship, regardless of the period selected. The relationship for the period 1981 to 1999 is shown on Plate 5.

Based on the above, the selected hydrologic base period for the WRI is rainfall years 1981 through 1999 (19 years). The October 1980 through September 1999 period meets the definition of a hydrologic base period:

- The position of the base period relative to historical wet-dry cycles is appropriate. If a smooth curve is fitted to the precipitation patterns, the base period covers one full cycle, including wet, dry, and average precipitation years (refer to Plate 4).
- The base period ends in 1999, which incorporates recent cultural conditions.
- The precipitation is similar for years leading into the beginning and end of the base period.

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CHAPTER 2 - DESCRIPTIVE GEOLOGY

2.1 INTRODUCTION

The District has benefited from several regional geologic and hydrogeologic studies of the Central Valley (Bertoldi et al, 1991; Page, 1986), as well as in and immediately adjacent the District (Croft, 1968). These important works substantially defined and described the basic geology and hydrogeology of the area in and surrounding the District, the vertical movement of groundwater, the effectiveness of the Corcoran Clay as a confining unit (now largely compromised) and regional groundwater flow patterns. As previously mentioned, it should be noted that the District is contained within a somewhat larger basin known as the Kaweah Basin, which in turn is a subset of the larger San Joaquin Valley Hydrologic Unit as defined by the DWR. The boundaries of the District are political and are not controlled by either geologic or hydrogeologic features. Hence, the term "basin" as applied to the District is not strictly appropriate.

Chapter 6 of this final report provides a discussion of the geology and hydrogeology of the District with emphasis on the water-bearing deposits and aquifer systems that control and influence recharge and patterns of groundwater flow. A related objective of the task was to populate a GIS database. To accomplish this, lithologic logs available from the District, the DWR, the California Department of Conservation, DOGGR, and other sources were compiled, reviewed, and selectively entered into a GIS database. Over 5,000 lithologic logs were compiled and reviewed. Using these data and other sources, a series of maps and cross sections of the District were prepared including:

- Study Area Location Map
- Regional Geologic Map
- Well Database and Cross Section Location Map
- Approximate Base of Permeable Sediments
- Approximate Top of Basement Complex
- Contours of Equal Specific Yield
- Base of Oxidized Older Alluvium Contour Map
- Structural Contours of E (Corcoran) Clay Member of Tulare Formation
- Hydrogeologic Sections A-A' through F-F'
- Soil Infiltration Map

A considerable amount of the work associated with this task involved the development and population of the GIS database and the generation of the various maps and cross sections. Because field work and independent research on the framework and descriptive geology (vis a vis, available references) was not performed, the text in this report derives directly from earlier work performed by Croft (1968), Davis et al. (1957), and B&E (1972). To assist the reader, a Glossary of Terms is provided as Appendix A.

2.2 METHOD OF STUDY AND NATURE OF THE DATA

The approach used in the study of the geology and the delineation of aquifer/aquitard units in the District followed standard techniques. The DWR was contacted to review and obtain logs (well completion reports) of water wells drilled within the District (and the immediately surrounding area). Some 3,000 well logs with lithologic descriptions and well completion information were obtained. For the most part, these well logs dated from about 1970 to late 1990; the vast majority of these well logs provided information as to location by section within a Township and Range. For most wells, no alphabetic designation within a section had been assigned by DWR staff from either field checking or by using sketch maps contained on the logs. Appendix B - Well Numbering System, provides a description of the well numbering system used in this report.

In addition to logs available from the DWR, the District had well completion reports for approximately 3,000 additional water wells drilled within the District prior to 1970 (compiled as part of the B&E study). These logs were similarly reviewed and selected for entry into the GIS database. Oil and gas logs drilled in the District available from the DOG were also obtained and entered into the GIS database. Specific locations for most wells in the District data set were also often not available. The location of such wells was similarly assigned to a center point of each Section. Eventually, some 600 well logs and geophysical electric logs were entered into the GIS database. Appendix B provides a summary of attributes for all wells included in the GIS database (refer to Plate 12 - Well Database of Cross Section Location Map). The database continued to be populated with additional information in subsequent tasks of the WRI, such as water level data, and used for the generation of water level hydrographs of key wells, for the development of water level contour maps, and to calculate annual changes of groundwater in storage for each hydrologic unit in the District.

Fugro uses Environmental Systems Research Institute (ESRI) ArcView GIS, the world's leading GIS software. ArcView is a powerful tool for organizing, creating, analyzing, and displaying data. The program also allows the user to develop customized modules using Avenue or Visual basic programming. The GIS database for the WRI project was constructed from a combination of existing data and interpretations of the existing data. Data was input from various sources, in various formats, and in various coordinate systems. Table 11 - GIS Data Input summarizes the data.

As mentioned, approximately 6,000 water well logs and 50 oil and gas well logs were initially screened for completeness and reliability of information. The lithologic descriptions for about 600 well logs were entered into the GIS database, but limited to a classification of clay, sand, and silty sand to represent non-permeable, permeable, and semi-permeable sediments. For each of the wells, information as to coordinates, depth, date, type of well, depth to the E (Corcoran) clay, etc., was entered. All electric logs available for water wells and oil and gas wildcat wells were also scanned, digitized, and entered in to the GIS database.

Table 11. GIS Data Input

Data	Feature	Source	Original Format	Coordinate System	Modifications
Hydrologic Boundaries	Polygon	KDWCD	CAD drawing		Reprojected and edited to match section lines
District Boundary	Polygon	KDWCD	CAD drawing		Reprojected and edited to match section lines
Cities	Point	ESRI sample data			Reprojected and edited to match section lines
Cities	Polygon	TIGGER data			Reprojected
County boundary	Polygon	USGS			Reprojected
Small water systems	Point	County of Tulare	Table of latitude/longitude coordinates		Created point shapefile, reprojected
Township/range/sections	Polygon	CA geospatial information library			Reprojected, clipped
Precipitation	Polygon	CA geospatial information library			Reprojected, clipped
Precipitation stations	Point	NOAA	Table of latitude/longitude coordinates		Created point shapefile, reprojected
Streams	Lines	USGS			Reprojected
Regional Geology	Polygon	CA geospatial information library			Reprojected, clipped
Land Use	Polygon	DWR			Merged from several sources
Soils map	Polygon	NRCS			Merged from several sources
District wells	Point	Kaweah Water District			
DWR wells	Point	DWR web site	Table of latitude/longitude coordinates		Created point shapefile, reprojected
USGS wells	Point	USGS web site			
Oil and gas wildcat wells	Point	Dept of Oil and Gas	Paper map		Digitized
Tulare county wells	Point	DWR			
Animal Operations	Point/polygon	Tulare County			
Aerial photos (1996,1999)	Image	DWR			Reprojected
Digital Elevation model	DEM	USGS			Merged several DEMs, reprojected
Hillshade of elevation	Hillshade	USGS			
USGS Quad index	Polygon	USGS			
District cultural features	Lines/Polygons	Kaweah Water District			
Electric logs	XCEL table	DWR/DOG	Paper electric logs	None	Digitized as lines, then converted to tables of depth versus resistivity
Well lithology	XCEL table	DWR	Paper well logs	None	Entered soil type and depth into tables
Corcoran Clay contours	Lines	B&E et al.	Paper map	Lat/Long	Digitized and coded by elevation
Specify yield contours	Lines	Davis et al. (1957)	Paper map		Digitized
Base of permeable sediments	Lines	Croft (1968)	Paper map		Digitized and coded by elevation
Geology	Polygons	Croft (1968)	Paper map		Digitized and coded by geologic unit
Top of basemap complex	Lines	Croft (1968)	Paper map		Digitized
Elevation contours	Lines	USGS DEM	Created in ArcView		Contours of DEM

Routines were then developed for creating cross sections from a variety of subsurface data. The cross sections included lithology, color-coded by soil type, electric log profiles, topography from the USGS digital elevation model (DEM), the interpreted elevation of the top of the Corcoran clay surface, the base of permeable sediments, specific yield variations, etc.

Cross sections were then automatically created from the database by using the basic premise behind the GIS features. The database is not only points, lines, or polygons on a map, but is also linked to tables of information. For example, each of the well logs and electric logs are points on a map and each point is linked to a table of information about the point such as the elevation of the well, the well lithology, or the electric log data.

The GIS database also contains layers that are in the same coordinate system. As a result, maps can be created from any combination of layers and data can be viewed in relation to other data from various sources. An accurate base map is key to the entire project, because all other layers are created based on that base layer. A base map from various cultural features (roads, city boundaries, district boundaries) was initially created and then other maps formatted as appropriate by turning layers on and off.

2.3 PHYSIOGRAPHY OF THE DISTRICT

The District is located on the east side of the south-central portion of the San Joaquin Valley. The San Joaquin Valley, which is the southerly part of the great Central Valley of California, extends from the Sacramento-San Joaquin Delta area on the north about 250 miles to the Tehachapi Mountains on the south. In the vicinity of the District, it is approximately 65 miles wide (refer to Plate 1). The Valley is bordered on the east by the Sierra Nevada, which range in elevation from about 1,000 feet or less to more than 14,000 feet above sea level. The Coast Range, which borders the Valley on the west, rises to about 6,000 feet above sea level.

The southern end of the San Joaquin Valley, also known as the Tulare Basin, is a closed feature without external surface drainage. Tributary streams drain to depressions, the largest of which is Tulare Lake bed located to the west of the District's boundary. The Kings, Kaweah, and Tule Rivers and, on occasion, the Kern River, discharge into Tulare Lake at times when flows exceed the capacity of foothill reservoirs and of the irrigation diversion systems.

The east side of the Valley constitutes a broad plain formed by large coalescing alluvial fans of streams draining the western slope of the Sierra Nevada. The Kaweah River alluvial fan or delta is separated from the large Kings River fan on the north by Cross Creek. On the south, Elk Bayou separates the Kaweah River fan from the Tule River fan. Cottonwood Creek, an intermediate stream between Kings and Kaweah Rivers, discharges onto the interfan area of these two systems. An excellent representation of the interfan areas within the District is provided by Davis et al. (1957).

The Kaweah River fan is the most important fan complex in the District and is characterized by a surface of low topographic relief, with variations rarely exceeding 10 feet except in stream channels. Elevations of the District vary from about 500 feet above sea level near the easterly boundary to about 200 feet at the westerly boundary. District lands generally slope in a southwesterly direction at about 10 feet per mile, with this slope lessening as the westerly boundary is approached.

In the easterly part of the District, surface soils are sandy and permeable, generally grading to finer materials to the west. In the interfan areas adjacent to Elk Bayou and Cross Creek, soils are alkaline and less fertile than in the remainder of the District. The Kaweah River fan is characterized by a network of natural channels of the Kaweah River and its distributaries as well as numerous canals constructed for irrigation purposes. The infiltration characteristics of surficial soils in the District are described in a later section of this report.

2.4 GENERAL GEOLOGY

As shown on Plate 13 - Regional Geologic Map, the rocks that crop out in the District include a basement complex of pre-Tertiary age consisting of consolidated metamorphic and igneous rocks, and unconsolidated deposits of Pliocene, Pleistocene, and Recent age, all of which contain fresh water. Consolidated marine rocks of Pliocene age and older do not crop out in this area but are penetrated by wells in the subsurface. Because the water from those wells generally is brackish or salty, the marine rocks are not considered as part of the fresh-water reservoir and constitute the effective base of fresh water (or permeable sediments). Most of the groundwater pumped within the District area is from the unconsolidated deposits and they have therefore been studied in greater detail (Croft, 1968) with reference to their water-bearing properties.

Geologic units that affect the occurrence and movement of groundwater in the District are generally classified and described as follows:

1. Basement Rocks: Non-water-bearing granitic and metamorphic rocks.
2. Marine Rocks: Non-water-bearing marine sediments including the San Joaquin Formation.
3. Unconsolidated Deposits: Nonmarine, water-bearing material comprised of the Tulare Formation and equivalent units.
4. Alluvial Deposits: Coarse-grained, water-bearing alluvial fan and stream deposits including older oxidized and reduced units, and younger alluvium.
5. Lacustrine and Marsh Deposits: Fine-grained sediments representing a lake and marsh phase of equivalent continental and alluvial fan deposition.

A useful summary of the main geologic and hydrogeologic units adapted from a variety of sources can be found in Bertoldi et al. (1991) and is provided below as Table 12 - Geologic and Hydrologic Units, San Joaquin Valley. Cross sections A-A' through F-F' are presented as Plates 14 through 19, respectively, depict subsurface geology of the District. Plate 12 - Well Database and Cross Section Location Map is to be used with the cross sections.

Table 12. Geologic and Hydrologic Units, San Joaquin Valley

Age	Generalized section of geologic units. Reported maximum thickness, in feet, is in parentheses (adapted from Page, 1986, table 2)	Hydrologic unit used in many reports such as Poland and Lofgren (1984)	Layers in digital flow model (Williamson and others, 1989)
Quaternary	**Flood basin deposits (100)** -- Primarily clay, silt, and some sand; include muck, peat, and other organic soils in Delta area. Restrict yield to wells and impede vertical movement of water. **River deposits (100±)** -- Primarily gravel, sand, and silt; include minor amounts of clay. Among the more permeable deposits in valley.	Upper water-bearing zone[1]; unconfined to semiconfined Principal confining unit (modified E Clay) / Absent	**Layer 4** Many wells tap this layer; unconfined storage
Tertiary and Quaternary	**Lacustrine and marsh deposits (3,600+)** -- Primarily clay and silt; include some sand. Thickest beneath Tulare Lake bed. Include three widespread clay units -- A, C, and modified E clay. Modified E clay includes the Corcoran Clay Member of the Tulare Formation. Impede vertical movement of water.	Lower water-bearing zone[1]; semiconfined to confined. Extends to base of fresh-water which is variable	**Layer 3** Many wells tap this layer; elastic and inelastic confined storage
	Continental rocks and deposits (15,000) -- Heterogeneous mix of poorly sorted clay, silt, sand, and gravel; include some beds of mudstone, claystone, shale, siltstone, and conglomerate. Form major aquifer system in valley.	Base of freshwater	**Layer 2** Some wells tap this layer; elastic and inelastic confined storage
Tertiary	**Marine rocks and deposits** -- Primarily sand, clay, silt, sandstone, shale, mudstone, and siltstone. Locally yield fresh water to wells, mainly on the southeast side of the valley but also on the west side near Kettleman Hills.	Below the depth of water wells. In many areas, post-Eocene deposits contain saline water	**Layer 1** No wells; elastic confined storage

[1]The upper and lower water-bearing zones are undifferentiated where the modified E clay (includes Corcoran Clay Member of the Tulare Formation) is absent.

2.4.1 Basement Complex

The basement complex of pre-Tertiary age (map symbol pT) consists of metamorphic and igneous rocks. They underlie the Sierra Nevada and occur as resistant inliers in the alluvium and as linear ridges in the foothills east of the District. In the subsurface, they slope steeply westward from the Sierra Nevada beneath the deposits of Cretaceous age and younger rocks that compose the valley fill. Plate 20 - Structural Contour Map, Top of Basement Complex, shows altitude above or below sea level at which bedrock (presumably basement complex) was reported by drillers or interpreted from electric logs. Cross sections A-A' and B-B' (Plates 14 and 15) indicate escarpments that are interpreted as buried fault scarps associated with the Rocky Hill fault. West of the escarpments, the slope of the basement complex steepens. In the Tulare Lake area, an oil-test well failed to penetrate the basement complex at 14,642 feet below sea level (Smith, 1964).

The basement complex is at shallow depths in the Lindsay, Strathmore, and Ivanhoe areas and in the intermontane valleys where it is penetrated by many water wells. Near Farmersville and Exeter, the basement complex forms a broad, gently westward-sloping shelf overlain by 100 to 1,000 feet of unconsolidated deposits. In T17S/R24E (near Ivanhoe), the basement complex drops abruptly to about 2,000 feet below land surface, presumably due to faulting.

2.4.2 Marine Rocks

Although not shown on Plate 13 or on the geologic cross-sections, along the east border of the San Joaquin Valley, Tertiary rocks, mainly of marine origin, overlap the basement complex and underlie the unconsolidated deposits. Croft (1968) suggests this unit may locally include beds of continental origin in the upper part. In the District, the marine rocks do not crop out. The Tertiary marine rocks have locally been penetrated by oil- and gas-test wells in the east part of the District, and range in age from Eocene to late Pliocene and consist of consolidated to semiconsolidated sandstone, siltstone, and shale. They have traditionally been locally divided into several formations by geologists (Park and Weddle, 1959), but as they generally contain brackish and saline connate or dilute connate water unsuitable for most uses, they are treated here as one unit.

2.4.3 Unconsolidated Deposits

The unconsolidated deposits described in this report are equivalent to those that have been described in previous reports and are divided into several geologic units. In the Kettleman Hills, west of the District, Woodring et al. (1940) divided the unconsolidated deposits into the Tulare Formation and into older and younger alluvium. The Tulare Formation in the Kettleman Hills overlies the upper Mya zone (Woodring et al., 1940, p. 13), a fossil horizon at the top of the San Joaquin Formation. The Mya zone is reported in well logs beneath Tulare Lake Bed and is a prominent marker bed outside of the District that separates the marine rocks (described above) from overlying continental deposits. The base of the unconsolidated deposits is projected by electric log correlation from the upper Mya zone beneath Tulare Lake Bed, eastward to the top of marine rocks. The unconsolidated deposits of this report are equivalent to the continental deposits (map symbol QTc) from the Sierra Nevada of Klausing and Lohman (1964) and to the unconsolidated deposits as used by Hilton et al. (1963) and are shown as such on the cross sections.

The unconsolidated deposits thicken from zero along the western front of the Sierra Nevada to a maximum of about 10,000 feet at the west boundary of the District. The unconsolidated deposits in the District are divided into three stratigraphic units: continental deposits, older alluvium, and younger alluvium.

In the subsurface, the younger alluvium interfingers and/or grades laterally into the flood-basin deposits and into alluvium, undifferentiated. The older alluvium and continental deposits interfinger and/or grade laterally into the lacustrine and marsh deposits or into alluvium. In the subsurface, the older alluvium and continental deposits are also further subdivided into oxidized and reduced deposits on the basis of environment of deposition.

Unconsolidated deposits, which locally crop out east of the District and extend beneath the valley floor, were eroded from the adjacent mountains, then transported by streams and mudflows, and deposited in lakes, bogs, swamps, or on alluvial fans. The lithologic and water-bearing characteristics of the deposits are dependent upon several controlling factors, which include 1) environment of deposition, 2) the type of rock in the source area, and 3) competence (or energy) of the streams.

According to Davis et al. (1957), oxidized deposits generally represent subaerial deposition, and reduced deposits generally represent subaqueous deposition. Oxidized deposits are red, yellow, and brown, consist of gravel, sand, silt and clay, and generally have well-developed soil profiles. Reduced deposits are blue, green, or gray, calcareous, and generally are finer grained than oxidized deposits, and commonly have a higher organic content than the oxidized deposits. In some cases, the separation between the oxidized and reduced deposits can be identified on well logs based on lithologic color. Such delineation can of course be highly subjective. The coarsest grained reduced deposits were laid down in a flood plain or deltaic environment bordering lakes and swamps. Because of a high water-table in the east side of the District (particularly Hydrologic Unit I), the sediments have not been exposed to subaerial weathering agents. The finest grained reduced deposits were mapped as flood basin, lacustrine, and marsh deposits.

The oxidized deposits underlie the older and younger alluvium and throughout most of the District, the oxidized deposits are 200 to 500 feet thick. Based on work by Croft (1968), a structural contour map of the approximate base of the oxidized deposits has been prepared and is presented on Plate 22.

The oxidized deposits consist mainly of deeply weathered, reddish brown, calcareous sandy silt and clay and can, in most well completion reports, be readily identified when present. Beds of coarse sand and gravel are rare, but where present, they commonly contain significant silt and clay. The highly oxidized character of the deposits is the result of deep and prolonged weathering. Many of the easily weathered minerals presumably have altered to clay and, as such, are poorly permeable.

2.4.4 Lacustrine and Marsh Deposits

The lacustrine and marsh deposits of Pliocene and Pleistocene age consist of blue-green or gray gypsiferous silt, clay, and fine sand that underlie the flood-basin deposits and conformably overlie the marine rocks of late Pliocene age. In the subsurface beneath parts of Tulare Lake Bed, these beds extend to about 3,000 feet below land surface. Where the equivalent beds crop out in the Kettleman Hills on the west side of the valley, they were named the Tulare Formation by Anderson (1905, p. 181). The lacustrine beds and fossils of the Tulare Formation were mapped and described in detail by Woodring et al. (1940, p. 13-26) who considered the top of the Tulare Formation to be the uppermost deformed bed. Therefore, by this definition, all the deformed unconsolidated deposits would form the Tulare Formation.

In the subsurface around the margins of the Tulare Lake Bed, the lacustrine and marsh deposits form several clay zones that interfinger with more permeable beds of the continental deposits, alluvium, undifferentiated, and older alluvium. Because of contained fossils and stratigraphic relations to adjacent deposits, these clays are considered to be principally of lacustrine origin. Clay zones are generally indicated by characteristic curves on electric logs and thereby facilitate some areal correlations between adjacent logs as shown in hydrogeologic cross sections. Although as many as six laterally continuous clay zones have locally been defined in the southern San Joaquin Valley, only the most prominent of these clay zones known as the "E" Clay (or Corcoran Clay member) of the Tulare Formation is found within the District (refer to Plates 21, 14, and 15). Plate 21 shows structural contours of the top of the E Clay and various interpretations of the easterly extent or pinchout of this prominent confining layer. Clay deposits are nearly impermeable and yield little water to wells and that which is obtained is generally of poor chemical quality.

The E Clay is one of the largest confining bodies in the area and underlies about 1,000 square miles west of U.S. Highway 99. The beds were deposited in a lake that occupied the San Joaquin Valley trough and which varied from 10 to 40 miles in width and was more than 200 miles in length (Davis et al., 1957). The first wide-scale correlation of the Corcoran Clay was made by Frink and Kues (1954).

The E Clay extends from Tulare Lake Bed to U.S. Highway 99 and is vertically bifurcated near Goshen. It is about 140 feet thick near Corcoran and the average thickness is about 75 feet. The deposits near Corcoran are probably the thickest section in the San Joaquin Valley.

2.4.5 Reduced Older Alluvium

As previously mentioned, the reduced older alluvium (map symbol Qoar) is a moderately permeable arkosic deposit that is not exposed in the District. It overlies the continental deposits, interfingers with lacustrine and marsh deposits beneath Tulare Lake Bed, and interfingers with alluvium, undifferentiated, north of Tulare Lake Bed. Around the margin of Tulare Lake Bed, the reduced older alluvium interfingers with lacustrine deposits.

The reduced older alluvium consists mainly of fine to coarse sand, silty sand, and clay that were probably deposited in a flood plain or deltaic environment. Gravel that occurs in the oxidized older alluvium is generally absent. The deposits are sporadically cemented with calcium carbonate, according to logs of core holes made by geologists of the Bureau of Reclamation. Those descriptions imply, however, that the calcium carbonate is probably less abundant than in the underlying reduced continental deposits.

2.4.6 Oxidized Older Alluvium

The oxidized older alluvium (map symbol Qoao) unconformably overlies the continental deposits (refer to Plate 22). The beds consist of fine to very coarse sand, gravel, silt and clay derived for the most part from granitic rocks of the Sierra Nevada. Beneath the channels of the Kaweah, Tule and Kings Rivers, electric logs indicate that the beds are very coarse. In the interfan areas, metamorphic rocks and older sedimentary units locally contributed to the deposits and, in those areas, the beds are probably not as coarse as the beds beneath the Kaweah, Tule, and Kings Rivers. Fine-grained deposits occur in the channel of Cross Creek.

East of U.S. Highway 99, the contact of the older alluvium with the underlying oxidized continental deposits is well defined in electric logs. Structure contours, based on electric-log data, show the altitude above or below sea level of the base of the unit. The older alluvium thickens irregularly from east to west, and probably has filled gorges cut by the ancient Tule River in the underlying oxidized continental deposits near Porterville. The base of the deposits occurs 195 feet below land surface near Exeter, and declines to 430 feet below land surface near Visalia and Goshen. In the log of 18S/23E-12H1, the base of the older alluvium occurs about 200 feet beneath the E Clay.

2.4.7 Younger Alluvium

Younger alluvium (map symbol Qya) consists of gravelly sand, silty sand, silt, and clay deposited along stream channels and laterally away from the channels in the westerly portion of the District. Younger alluvium is relatively thin locally, reaching a maximum depth below ground surface of perhaps 100 feet. Except in the extreme easterly portion of the District, it is generally above the water table and does not constitute a major water-bearing unit.

Soils developed on younger alluvium show little or no profile development and are generally free of underlying clay subsoil or hardpan. Because percolation rates through the younger alluvium are moderate to high, this deposit serves as a permeable conveyance system for recharge to underlying water-bearing materials.

2.5 STRUCTURAL GEOLOGY

The structural geology of the District is relatively simple. In the eastern portion of the District and coincident with the western boundary of Hydrologic Unit I, the Rocky Hill fault disrupts pre-Eocene deposits and may locally penetrate older alluvial deposits. The linearity of the ridges in this area defines the fault line. Croft (1968) suggests that the Rocky Hill fault does not offset younger alluvium based on water level data. Nonetheless, the hydrologic connection of aquifers (oxidized alluvial deposits) may be restricted and warrants the location of the hydrologic unit boundary as shown.

The primary east-west geologic cross sections (A-A', B-B', and C-C') indicate a thickening section of unconsolidated deposits moving west across the District. The surface of the Tulare Formation is described by Woodring et al. (1940) as being modestly warped, suggesting regional folding during and after deposition. For the most part, such warping has little affect on the patterns of groundwater flow within the District (i.e., across the hydrologic unit boundaries) or at the perimeter boundaries of the District. Quantification of the magnitude of such is summarized in Chapter 3.

2.6 SPECIFIC YIELD

Specific yield is defined as the volume of water (or ratio of water that drains from the total volume) that will drain by gravity from sediments within a designated storage unit if the regional water table were lowered. Conversely, it is also defined as the volume of water to resaturate the deposits after they are drained (as long as the sediments do not collapse i.e., subsidence). With application to the District, specific yield is important in the estimates of annual storage changes in each of the hydrologic units over the defined base period or for comparison to earlier time periods.

To perform storage change estimates, well logs are typically reviewed and sediments assigned a specific-yield value based on grain size, degree of sorting, and a variety of other factors. The storage capacity of a given area can be estimated by multiplying the total volume of the deposits considered (within the range of water level fluctuation over the base period) by the coefficient of storage, which in this case is the specific yield. For the southern San Joaquin Valley, considerable study of storage changes and determination of specific-yield values for the major hydrologic units was accomplished in the 1950s by Davis et al. (1957). This work considered over 10,000 well logs in the southern San Joaquin Valley (about 1 log per square mile) to estimate the storage capacity of 16 areas of the Central Valley. The change in storage calculations considered water level variations from about 10 feet to 200 feet below ground surface, divided into three depth zones. Eight lithologic types were considered based on the well logs, each of which was assigned a specific yield value ranging from zero to 25 percent.

The District is contained within portions of two of the storage areas considered by Davis et al. (1957): the Kings River and the Kaweah-Tule storage units. Although no maps depicting equal contours of specific yield are presented in the report by Davis, various tables provide specific-yield values for each township and range within and adjacent to the District and by the three depth zones. The tables can accordingly be used to generate specific-yield contour maps for each of the hydrologic units of the District and for depths to 200 feet. Plate 23 - Contours of Equal Specific Yield presents a map of equal contours of specific yield for near-surface sediments in the District. A specific-yield contour map is also available for the northerly Alta Irrigation District (Kings River Conservation District, 1992) and was apparently used in a water balance and numerical model of the Alta area. The basis for the contour map presented in that report is not described.

The well log data compiled in this study, and which populate the GIS database of the District, also provide a means to develop specific-yield values and contour maps of the hydrologic units within the District. From these data and the information contained in Davis et al. (1957), some generalizations on the distribution and range of specific-yield values of the near-surface sediments in the District can be made. Most of the District is underlain by permeable deposits to depths of 200 feet, although there is considerable lenticularity and an overall fining of sediments to the west, as one would expect.

The average specific yield of the deposits within the 10- to 200-foot depth range is 9.9 percent, slightly below the valleywide average of 10.3 percent, but considerably above the average specific yield of any of the interstream storage units. Sand and gravel together make up 25.6 percent of the total thickness, also slightly below the valleywide average, which is 28 percent. Four-fifths of these coarse-grained deposits are reported as sand, one-fifth as gravel.

2.7 WATER INFILTRATION RATES

Infiltration characteristics of surficial soils in the District are based on published Soil Surveys prepared by the USDA National Resources Conservation Service, which groups soils into hydrologic groups based on soil texture, composition, and other factors. The Soil Surveys are available in digital format known as Soil Survey Geographic database (SSURGO). The U.S. Bureau of Land Management (BLM) recently developed a computer program, the Soils Suitability Extension (SSE) that provides an interface to ArcView.

The database and accompanying Soil Infiltration Map (Plate 24) were prepared using the following steps:

1. The SSURGO databases for Fresno, Kings, and Tulare Counties were downloaded from the NRCS website as ARC/INFO coverages and imported into ArcView.
2. The Soils Suitability Extension computer model (BLM, 2000) was used to rate soils on their relative infiltration capacity (high, moderate, slow, slow with wet soils, and very slow). This step was performed for each of the four SSURGO databases.
3. The individual databases were merged using the ArcView geoprocessing extension and then projected from decimal degrees into the State Plane coordinate system. The resulting merged database was "dissolved" on the infiltration field to join the adjacent matching polygons. The dissolved shapefile was clipped to the project study area boundary.

The results of this GIS analysis show that most of the District is underlain by soils with "moderate" rates of water infiltration. Geologically, these correspond to areas of Holocene alluvium. Areas of slow infiltration are also common; these areas correspond to areas of Pleistocene alluvium. Scattered pockets of high infiltration soils appear to be associated with stream channels and associated deposits. A distinctive feature on the map is the straight boundary between some of the infiltration polygons. This boundary coincides with the Kings and Tulare County boundaries and is an artifact of the different Soil Surveys prepared for each of these counties.

The infiltration characteristics of surficial soils in the District can be used in the preliminary evaluation of potential recharge sites. It should not be used as the sole source of information and is not a substitute for site-specific studies. Other factors, such as available water capacity, amount and timing of precipitation, underlying geology, and land use, influence the suitability of recharge sites and need to be evaluated in siting recharge facilities. The map was also used to assist in assigning estimated values of deep percolation and effective rainfall as part of the water balance.

CHAPTER 3 - GEOHYDROLOGY

3.1 INTRODUCTION

In cooperation with the DWR, the District measures, tabulates, and publishes water level data for as many as 400 water wells. Records for some wells extend back to the 1920s; most records for wells included in the District's groundwater monitoring program, however, extend back to the 1950s. The quality of these data is considered excellent. From these data, changes in groundwater in storage can be estimated, and this chapter presents the findings of such storage changes, a descriptive analyses of water level conditions and trends within the District and each hydrologic unit for the base period (and several preceding periods), and comments on aquifer numerical properties and the estimated volumes of subsurface flow occurring within the District and to and from the District. These data are used later as part of the hydrologic budget for the District.

The GIS database presented in Chapter 2 provides the framework to calculate storage changes and groundwater flow by integrating groundwater level elevation contour maps with specific yield data, aquifer properties and District/hydrologic unit areas. As mentioned, the District benefits from a long-term water level measurement program of key wells in the District from which the DWR has manually created "Spring, Unconfined Aquifer System" contour maps for each year of the base period. The DWR also published, up until 1989, water level elevation contour maps for the "pressure system" aquifer of the San Joaquin Valley. Such data and maps were obtained for comparison to the unconfined aquifer.

This water level database is posted on the DWR website and allows downloading of compiled hydrographs of key wells in the District for purposes of graphical display and analysis. Total volumes of groundwater in storage were estimated from these maps for each year of the base period, the results of which are provided in this report.

3.2 AQUIFER CHARACTERISTICS

3.2.1 Availability of Data

Hydrogeologic parameters of the aquifers and aquitards in the District include average specific yield values for the upper 200 feet of sediments and numerical values of transmissivity, hydraulic conductivity, and specific capacity. For the most part, reliable coefficients of aquifer storage (storativity) can only be generated from controlled pumping tests with observation wells; few such data exist within the District.

Regional aquifer system numerical properties can be found in reports by Bertoldi et al. (1991), which provides average hydraulic conductivity values and storage coefficients for the entire Central (San Joaquin) Valley. For the most part, such data provide a broad range of aquifer numerical values that can be used for comparative purposes only. Within the District, focused studies at the Visalia Landfill (Malcolm Pirnie, Inc., 2001), for canal lining (B&E, 1997), for aggregate mining applications (Jones & Stokes Associates, Inc., 1997) and studies of the adjacent Tule Basin area (Naugle, 2001) provide a more applicable and narrower range of aquifer parameters for the District. Harter (2002) also analyzed Southern California Edison (SCE) data (efficiency tests) for several hundred wells within the Tule and Kaweah basins and converted well-specific capacity data (typically based on a 1-hour pump test) to transmissivity using a conversion factor of 1,500 (Driscoll, 1987). The approach is similar to that done by B&E and the USGS. The data were analyzed statistically and a single horizontal hydraulic conductivity value entered for a section (if data were available). The results of Harter were applied to the District, and are shown on Plate 25 - Horizontal Hydraulic Conductivity Map. An attempt was made to contour the data, but the results were not considered meaningful.

For purposes of calculating the seasonal volumes of subsurface groundwater flow within the District, the aquifer parameter of interest is that of horizontal hydraulic conductivity, typically expressed in feet per day (ft/day) or gallons per day per square foot (gpd/ft^2). The sources listed above provide a range of values that reflect the broad geographic area of the entire Central Valley, the aquifer system considered, and how the value was either measured or derived. For an area as large as the District, which contains a heterogeneous mixture of aquifers, aquitards, and aquicludes, the published values fall within several orders of magnitude (particularly considering the aquitard deposits). A summary of reference hydraulic conductivity values (or permeability) is provided in Table 13 - Summary of Aquifer Hydraulic Conductivity Values.

Table 13. Summary of Aquifer Hydraulic Conductivity Values

Reference	Aquifer System	Representative Horizontal Hydraulic Conductivity Values (gpd/ft^2)
CH2M Hill/Fugro West, Inc. (in Dames & Moore, 1999)	Semiconfined	750
Naugle (2001)	Alluvial unconfined Continental deposits, confined	70 to 1,000 7 to 80
Croft & Gordon (USGS, 1968)	Alluvial unconfined Continental deposits, confined	10 to 100 1 to 270
Alta Irrigation District Groundwater Model (Kings River Conservation District, 1992)	Semiconfined aquifer	80 to 1,270
USGS Central Valley Model (Bertoldi et al., 1991)	Confined aquifer	About 20
Ludorff & Scalmanini (in Jones & Stokes, 1997)	Alluvial unconfined	15 to 20
Schmidt (1994)	Semiconfined	10 to 200
Harter (2002)	Unconfined to Confined	1 to 750
Southern California Edison (July 2002)	Unconfined to Confined	About 100 to 1,000

As indicated in Table 13, the horizontal hydraulic conductivity values range from about 1 gpd/ft^2 for the confined aquifer found in hydrologic units west of U.S. Highway 99 (Units V and VI) to as high as 1,000 gpd/ft^2 in the easterly part of the District. The published values are clearly gross estimates of this aquifer parameter.

Determination of average specific yield values in the District (by township and range) were described in detail in Chapter 2 (Plate 23) and derive from work by Davis (1957). Specific yield volumes ranged from about 6.5 to as high as 13.7 percent. Calculations of the annual changes of groundwater in storage in the District rely on these values. Estimates of the *total* volumes of groundwater in storage were similarly based on work by Davis, weighted according to the thickness and distribution of aquifers and aquitards throughout the District. The application of such "average" values is considered an approximation only.

3.2.2 District Aquifer Numerical Values

B&E (1972) provides a discussion of average coefficients of hydraulic conductivity values for "typical" aquifer systems in the District. These aquifer systems include the younger alluvium and older alluvial deposits associated with Kaweah River fan deposits, and continental deposits both above and below the Corcoran clay (E-clay). These units are, for the most part, the same as the contoured elevations of the major units developed in Chapter 2. Average coefficients of horizontal hydraulic conductivity in gpd/ft^2 were derived by B&E from a tabulation of pump test data from various sources including the USGS and from an independent review of SCE pump efficiency or hydraulic efficiency tests for about 200 wells in the District. The locations of such wells used by B&E are not provided. The USGS data referenced by B&E presumably derive from Croft and Gordon (1968).

For the purposes of this report, the B&E data (1972) were to be supplemented by additional SCE efficiency test data. Such data were provided in July 2002 but could not be tied to a specific well or location. A general geographic area was noted, as well as such information as date of test, water level, well yield, drawdown and plant efficiency. Data for approximately 1,150 tests were provided. Given the lack of specific information contained in the test data, it was considered a reliable but not directly useful source of data to refine the estimates of horizontal hydraulic conductivity values for aquifers in the District. The data were, however, compiled and used to present well specific capacity data for the District. Although the work of Harter (2002) provides a useful source of additional aquifer hydraulic conductivity data for the District and areas to the south, the data provided by B&E (1972, Table VI-1) is considered to provide a reasonable range of permeability values from which estimates of annual volumes of subsurface flow can be made. For the most part, the data are consistent with data contained in Table 13. It should be noted that all such estimates are approximate. SCE data provide the specific capacity for a particular well (in gallons per minute per foot of drawdown), which is dependent on the manner of well drilling and development, age of the well, well design, and a variety of other factors. The specific capacity value is then used to estimate the aquifer permeability or horizontal hydraulic conductivity. For purposes of this study, the B&E data are considered acceptable. Aquifer parameter values used to evaluate subsurface flow are provided below in Table 14 - Aquifer Numerical Values.

Table 14. Aquifer Numerical Values

Hydrologic Unit No.	Aquifer System	Average Thickness of Saturated Aquifer (feet)	Average Coefficient of Permeability (gpd/ft^2)
I	Older alluvium (oxidized)	150	750
	Older alluvium (residual)	50	500
II, III, IV	Older alluvium (oxidized)	250	500
	Older alluvium (residual)	250	250
	Younger continental deposits	150	150
	Older continental deposits	800	70
V	Older alluvial deposits	150	250
	Younger continental deposits	150	150
	Older continental deposits	800	70
VI	Older alluvial deposits	100	250
	Younger continental deposits	200	150
	Older continental deposits	1,000	70

The values above were used with the GIS database to calculate volumes of subsurface flow, the details of which are provided later in this chapter.

3.3 WATER LEVEL CONDITIONS

3.3.1 Availability of Data

Water level data from the DWR database were used to generate hydrographs for approximately 100 water wells within the District. The location of wells for which hydrographs were created are shown on Plates 26 through 31 - Hydrographs of Selected Wells. Criteria for selection of a well for purposes of graphical presentation on these plates was 1) frequency of measurement, 2) duration of record, 3) geographic distribution within the District, and 4) well design information. Most wells within the District's water level measurement program provide excellent records of both Spring and Fall water level conditions and many contain measurements that extend back to the 1950s. Some 500 water level hydrograph records were reviewed and about 100 wells selected that provided a good geographic distribution of variations and trends.

For the approximate 100 wells hydrograph records used, each was compared to information contained in the GIS database or on well driller's reports for information on perforated interval. Almost exclusively, it was determined that no specific information on well depth and perforated interval are available for wells in the entire water level data collection program. Given the heterogeneity of aquifer properties in the District and known aquitards present in the west part of the District, there was accordingly no ability to separate out water level data representative of the confined or unconfined aquifer systems. Staff at the DWR offices in Fresno and Sacramento were questioned as to whether they had ever "qualified" wells for inclusion in the water level data collection programs with respect to perforated interval. Conflicting answers were provided; in any event, no such supporting data were obtained. As a general observation, wells located east of the Corcoran clay reflect water level conditions representative of the unconfined aquifer system. Wells located within the area of the Corcoran clay are, for the most part, perforated in the confined aquifer system.

B&E (1972) provides some distinction between unconfined and confined water elevation surfaces within the District. The basis for such separation and which wells were used for contouring is not known. B&E also noted that "it was found that many of the wells measured drew from more than one aquifer system and water level measurements therein reflected a composite of the water levels." As noted by Bertoldi et al. (1991), the regional groundwater flow pattern in the Central Valley is strongly influenced by numerous clay and silt lenses. Two concepts of flow can be advanced that would apply to the District. The concepts of flow consider: 1) an unconfined and confined aquifer system separated by a regional aquitards (such as the Corcoran clay), and 2) a flow system consisting of a single heterogeneous aquifer with varying vertical leakage. The latter concept would appear to prevail in the District based on the hydraulic response of the aquifers to pumping.

Many wells in the District west of U.S. Highway 99 penetrate and perforate aquifers above and below the Corcoran clay and provide significant vertical leakage and hydraulic communication, which affects the pattern of groundwater movement and rates of regional recharge and discharge. An example of the significance of such direct leakage and communication between aquifers can be found in Malcolm Pirnie, Inc. (2001). The natural groundwater flow system has also been greatly altered by large-scale diversions and redistribution of surface water and conjunctive use programs.

For that portion of the District west of U.S. Highway 99, confined and semiconfined groundwater conditions also exist and, to the extent the piezometric surface in the confined aquifer (beneath the "E" clay or Corcoran clay) differs significantly from the unconfined water level surface, the total change of groundwater in storage also needs to consider storage changes in the confined (pressure) aquifer. The DWR prepared annual "pressure" system water level maps for the San Joaquin Valley through 1988 and such maps are available and were obtained for the District area from about 1980 to 1988. Pressure system contours were drawn by the DWR for the area surrounding and north of Corcoran; typically, only several pressure system contour lines were present for each year in this District area (southwest margin of the District). These contours were digitized and a series of profiles constructed to show the relationships between the unconfined aquifer system water level, the elevation of the top and bottom of the "E" clay, and the elevation of the pressure system water level. In all years, the water level in the unconfined system and the pressure system differed by no more than 20 feet and were substantially above the "E" clay. The data (at least for the District) support a more or less common water level between the two aquifer systems. Considerable interaquifer groundwater flow must occur between the two systems (via wells with perforations in both systems). Storage change calculations for the unconfined system appears appropriate for both systems and for the purpose of the water balance and perennial yield calculations.

3.3.2 Water Level Fluctuations

Specific to the District, aquifers occur in unconfined, semiconfined, and confined states. Water levels in an unconfined aquifer system coincide with the top of the zone of saturation, where hydrostatic pressure is equal to atmospheric pressure. Seasonal water level variations in such systems are typically subdued. In confined or artesian aquifers, waterbearing materials are completely saturated and are overlain by confining materials of low permeability, such as clay and fine silt, and water within the aquifer is under hydrostatic pressure. The hydrostatic head, or pressure, in such an aquifer is reflected by the height above the confining stratum to which water will rise in a well drilled into the aquifer. With the exception of Hydrologic Unit No. I, water level variations in the District display confined aquifer responses.

Because the alluvial and continental deposits in the District are characteristically heterogeneous in composition, containing individual strata of low permeability that generally exhibit little or no continuity, most aquifer systems are, in fact, semiconfined. Such aquifers respond to pressure changes over short periods of time, but hydrostatic heads reach equilibrium with unconfined water table over extended periods of static, nonpumping conditions.

Water level conditions in the District are presented in a series of contour maps of equal groundwater elevation for each year of the base period, and two prior periods dating from the Spring of 1952 and the Fall 1971 (refer to Plates 32 and 33). The 1971 period derives from B&E (1972); all other data derive from the DWR. The general pattern of groundwater movement in the District reflects recharge entering the District from the surface water (stream) systems of the Kaweah, the Tule, and, to a lesser extent, the Kings River. The pattern of flow from northeast to southwest across the District is characteristic, regardless of period. Significant alternations of this pattern are apparent in pumping depressions in and about the City of Corcoran, between Visalia and Hanford, and northwest of Exeter. The size and configuration of the pumping depressions are variable, and over the 1981 to 1999 base period clearly reflect the magnitude of and increases in groundwater extractions from about 1987 to 1994 when the supply of surface water was reduced. Conversely, replenishment to the aquifer systems in and southeast of Hydrologic Unit No. IV near Lindsay is apparent in the water level contours as a persistent rise in water levels in this area over the base period. A greater reliance on surface water in this area over the last 20 years is surmised, and possibly changes in land use.

During the base period, there is a characteristic pattern to the water level hydrographs in the District. For the most part, water levels in the District from about 1982 to 1986 reflect a general rise, followed by sharp declines from about 1987 to 1994, followed by a general rise. Plates 26 through 31 reflect these patterns and represent water level fluctuations in typical wells within each of the hydrologic units and aquifer systems in the District. These hydrographs show annual and cyclical fluctuations in groundwater levels, reflecting climatic conditions and magnitude of replenishment, extractions of groundwater, and the hydraulic conductivity of the aquifer system or systems penetrated by each well.

3.3.3 Base Period Water Level Conditions

Water level variations over the base period responded to the cyclical nature of water supply and deficiency related to surface water supplies and deliveries from the Kaweah River system. District-wide high water levels occurred during the mid 1980s; and District-wide (locally historic) low water levels occurred in about 1995. In general, a characteristic northeast to southwest pattern of groundwater flow occurred throughout the base period. Areas of pumpage depressions are persistently present north of Corcoran, west of Visalia, and northwest of Exeter. An overall discussion of annual water level conditions over the base period is provided in Table 15 - Summary of Water Level Conditions.

Water level conditions in the District over the base period are presented as Plate 39 - Contours of Equal Differences in Water Levels, 1981 to 1999 and indicate that stable (i.e., little or no net change in water levels) prevailed over much of the District. In certain areas, water level rises on the order of 10 to 20 feet occurred. Pronounced declines occurred in the west part of Hydrologic Unit No. VI, reflecting greater reliance on groundwater in the area over the last 20 years. Such water level declines in this area were anticipated by B&E (1972).

Plate 40 - Contour of Equal Difference in Water Levels, 1981 to 1995 reflects the broad, District-wide declines, and in many cases, historic low water levels in the District that emerged by about 1995. Groundwater storage depletion in 1995 for the District as a whole (compared to 1981) were on the order of 1 million af. In 1995 the most significant declines were apparent northwest of the City of Corcoran.

3.3.4 Historical Variations

Long-term variations of water levels in the District can be seen on Plate 41 - Contours of Equal Difference in Water Levels, 1952 to 1999. The period 1952 is an arbitrary starting point, and was chosen for comparison in that a District-wide DWR water level contour map existed for 1952. The 1952 comparison is, however, an appropriate period to consider with respect to the hydrologic cycle (refer to Plate 4). The period is somewhat "neutral" with respect to the extremes of wet or dry periods. Inspection of Plate 41 indicates significant water table declines along the west side of Hydrologic Unit No. VI (City of Corcoran to the City of Hanford) as well as east of Hanford. Some areas in the District have experienced significant rises in water levels (in areas as much as 40 feet), such as in Hydrologic Unit No. IV. Such changes presumably reflect a shift from a reliance on groundwater to surface water.

3.3.4.1 Hydrologic Unit No. I

The water well hydrographs for Hydrologic Unit No. I (refer to Plate 26), are representative of fluctuations in the unconfined water surface in the alluvial deposits of the Kaweah River fan deposits. For the most part, the water level variations reflect stability and consistency of replenishment (e.g., Well No. T17S/R27E-34P1). Water level variations are seasonally small (often within a range of 20 feet or less) for at least the last 50 years. For most of Hydrologic Unit No. I, groundwater levels are within 20 feet of ground surface. This unit has limited storage capacity and a shallow depth to the base of permeable sediments.

Table 15. Summary of Water Level Conditions

Year	Comment
1952	Southwest direction of groundwater flow across District. Recharge from Kaweah system prominently displayed, lesser so from Kings River system north of Hydrologic Unit No. VI and Tule River southeast of Hydrologic Unit No. IV.
1971	Southwest direction of groundwater flow prevails across the District.
1981	Prominent pumping troughs (3) north of Corcoran, between Corcoran and Tulare, west of Visalia. Small pumping trough northwest of Ivanhoe. Recharge from Kaweah system evident with general southwest direction of groundwater flow across District.
1982	Water level conditions similar to 1981, but growth of pumping trough between Hanford and Corcoran evident. Overall declines in water levels District wide.
1983	District-wide recovery in water levels. Pumping trough north and east of Corcoran separates.
1984	Continuation of water level rise throughout District. Pumping depressions still present in Hydrologic Unit Nos. V and VI, but water levels as much as 30 feet higher than in 1981. Same pattern of groundwater flow and recharge sources.
1985	Water levels stable to slightly decreasing. Expansion of pumping depression west of Visalia.
1986	Same general pattern of groundwater movement and water levels as existed in 1985.
1987	Generally stable to slight increase in water levels District wide. 250-foot elevation contour reaches U.S. Highway 99.
1988	Beginning of 7 consecutive years of deficient water supply to the District. Same general pattern of groundwater movement southwest across District.
1989	Water levels falling throughout entire District.
1990	Significant pumping troughs emerging in Units VI and VI, and District-wide declining water levels. 250-foot elevation contour records to 3 miles east of U.S. Highway 99.
1991	Continuation of declining water levels District wide. Pumping trough north of Corcoran reaches elevation of +110 feet. Pumping troughs west of Visalia and north of Ivanhoe. Recharge contours from Kaweah system much less prominent.
1992	Water levels stable to declining. Expanse of pumping trough north of Corcoran.
1993	Pumping trough north of Corcoran falls below -100 feet and continues to expand. Pumping trough south of City of Tulare develops. Widespread falling water levels.
1994	Water levels District wide at or near historic low levels.
1995	Water level increases and recharge evident in east side of District. Widespread pumping trough still apparent north of Corcoran.
1996	Rising water levels District wide. Pumping trough still apparent in Units V and VI.
1997	Conditions similar to 1996. Recharge from Kaweah System apparent in groundwater elevation contours.
1998	Pumping troughs and depressed water levels apparent in Units V and VI. Water levels stable to recovering.
1999	Pumping troughs regressing in Units V and VI. Rising water levels with District-wide conditions similar to 1981.

3.3.4.2 Hydrologic Unit No. II

The water well hydrographs for Hydrologic Unit No. II show a more pronounced cyclical variation, reflecting semiconfined to confined conditions (refer to Plate 27). During the base period, reduced water supply/replenishment or recharge is evident in most hydrographs during the 1980s. The drought of the late 1980s to about 1995 (District-wide low water levels) is clearly evident in the rainfall records, and is for the most part mimicked in all hydrographs. The magnitude of water level variations in some hydrographs approaches 100 feet (e.g., Well No., T18S/R24E-13H2). For those wells that have records that extend back to the 1940s, there is local evidence of water table declines, and depletion of groundwater in storage. In some wells (e.g., Well Nos. T18S/R23E-34A1 and T18S/ R23E-15A1), the high water levels have not been achieved such as occurred in the mid 1980s. Since about 1960, water levels in Hydrologic Unit No. II have been stable.

3.3.4.3 Hydrologic Unit No. III

Water level trends and variations in Hydrologic Unit No. III are shown on Plate 28 and are similar to those observed in Hydrologic Unit No. II. Water level variations reflect semiconfined aquifers with water levels being seasonally variable by about 20 feet or so. Long-term water level declines are evident in Well No. T19S/R24E-3A1 (City of Visalia).

3.3.4.4 Hydrologic Unit No. IV

Water level variations and trends for Hydrologic Unit No. IV are shown on Plate 29. The geographic extent of this unit extends from near the apex of the Kaweah fan (unconfined aquifer system) to southwest of the City of Tulare where confined aquifer conditions exist. In the former area, seasonal water level variations are minor. South of the City of Tulare, a pumping depression is apparent (e.g., Well No. T21S/R24E-K1) with significant (almost 150 foot) declines in water levels in the confined aquifers during the early 1990s. Long-term water level data in the southwest part of Hydrologic Unit No. IV are, however, relatively stable. Replenishment of water from the Tule River system is strongly present in wells southeast of the District. Seasonal cyclical variations in the water levels are everywhere apparent.

3.3.4.5 Hydrologic Unit No. V

Historical water level variations for Hydrologic Unit No. V are presented on Plate 30. Virtually all hydrographs presented show pronounced cyclical seasonal and wet-dry period responses characteristic of confined aquifer conditions. Well No. T21S/R23E-5R1 northeast of the City of Corcoran is typical. Notable are high water level conditions in the mid 1980s that equal or exceed conditions in the 1940s (c.f., Well Nos. T19S/R23E-31R1 and T21S/R23E-5R1), suggesting a long-term balance and replenishment to meet the seasonal groundwater pumpage demands. Storage change calculations, however, indicate a water supply deficit of about 6,800 afy in this hydrologic unit. The stability of the water levels may be compensated by a significant component of vertical leakage between aquifers above and below the Corcoran clay.

3.3.4.6 Hydrologic Unit No. VI

Water level conditions and trends in Hydrologic Unit No. VI are similar to Hydrologic Unit No. V. Since about 1960, there are pronounced cyclical variations in the water level data, and an overall decline in water levels, particularly on the western edge (refer to Plate 31) is apparent. Some notable anomalies exist, however, such as Well No. T20S/R22E-7M1, which shows a significant rise in water levels (likely a shallow well).

3.4 GROUNDWATER IN STORAGE

3.4.1 Background

Seasonal variations in the volumes of groundwater in storage in the District and each hydrologic unit were calculated for each year of the base period using the water level elevation contour maps and the estimated specific yield values of the near-surface sediments presented in Chapter 2. For comparative purposes, total and useable volumes of groundwater in storage were also estimated for the District and each hydrologic unit from water level data in the early 1950s, for 1971 (end of the short-term base period used by B&E [1972]), and under current conditions.

Calculation of the total volume of groundwater in storage in the District considered a saturated sediment thickness extending from the water surface elevation to the base of permeable sediments as shown on the various hydrogeologic cross sections. Any such calculation is considered a gross estimate given the variations of specific storage contained in the various aquifers and aquitards, and the variable nature of the elevation of the base of permeable sediment within the approximate 340,000 acres of the District. The changes in storage for the approximate 50-year period from 1952 to 2000 were used to evaluate conditions of water supply surplus and deficiency, and in recognizing conditions of long-term overdraft. The changes in the estimated volumes of groundwater in storage are also used for comparison to the annual storage changes using the inventory method as part of the hydrologic budget.

3.4.2 Groundwater Storage Calculations

The volume of groundwater in storage in a basin controls its ability to tolerate periods of drought and/or extractions more than the average annual recharge rate. Areas with large volumes of groundwater in storage, such as the District, can tolerate extraction rates significantly greater than the average annual recharge rate for multiple years without significant impacts. Such impacts might include irreversible losses in well yield, subsidence, water quality deterioration, excessive pumping, etc. The period from about 1989 to 1995 is a good example. Areas with limited groundwater in storage, on the other hand, can experience water supply shortages relatively rapidly.

The total groundwater in storage is the volume of water existing within void spaces of the water-bearing materials. The amount of this void space that holds retrievable water is commonly known as specific yield or the coefficient of storage. Specific yield is the ratio of the volume of water that saturated sediment will yield by gravity drainage, in proportion to the total volume of the sediments. The ratio is dimensionless and is expressed as a percent. As discussed in Chapter 2, specific yield values for the District were estimated by Davis (1958) based on a comprehensive review of well log data for the area. These specific yield values were entered into the GIS database and a contour map of equal specific yield values developed for the District that can be applied to the depths within which changes in water levels occur.

The change in amount of groundwater in storage depends on the annual water supply surplus or deficiency, and is expressed in the general water balance equation. This equation considers both surface and subsurface water as they relate to water supply, use, and disposal during the base period. One method of determining the annual change of groundwater in storage involves use of the specific yield method. The water level contour maps form the basis of this method. Each map was prepared by plotting water level data and manually contouring the water surfaces. As previously discussed, the contours of the water level surfaces were done by DWR staff and represent Spring conditions of the "unconfined" aquifer for each year of the base period.

The annual storage calculations involved digitizing the contours for each year of the base period (as well as for 1952 and 1971), coding the contours by elevation, and creating automated routines in GIS to develop a gridded surface. These surfaces were used to calculate the specific changes in water levels between the Spring period of each year. The water surface changes were then integrated with the specific yield contour data and the average changes in groundwater in storage calculated, in afy. The resulting annual storage changes from 1982 to 1999 (18 years) for the entire District and for each hydrologic unit are presented in Table 16 - Estimated Annual Change of Groundwater in Storage.

GIS was also utilized to calculate the volume of saturated material between the water level contour surfaces extending to the base of the fresh water surface for 1952, 1971, 1981, 1995, and 1999 using average saturated sediment specific yield values of 6, 8, and 10 percent. This volume is commonly referred to as the total volume of groundwater in storage. These volumes were combined with the specific yield estimates to quantify and compare changes in the total amount of groundwater in storage for those respective years. The calculated annual total groundwater in storage values for the 5 specific years are presented in Table 17 - Estimated Total Groundwater in Storage for 1951, 1971, 1981, 1995, and 1999.

Table 16. Estimated Annual Change of Groundwater in Storage
(in acre-feet)

Year	Annual Change in Storage						
	Entire District	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI
1981	(172,412)	(2,684)	(9,994)	(17,872)	(37,401)	(43,916)	(60,545)
1982	486,797	9,600	40,327	47,137	96,146	157,591	135,996
1983	329,135	3,935	30,963	13,472	40,757	107,601	132,407
1984	(87,006)	(13,196)	(7,988)	265	(21,308)	(23,632)	(21,147)
1985	(118,171)	5,614	(11,808)	(11,649)	(26,941)	(34,032)	(39,355)
1986	209,644	(6,245)	13,044	27,552	31,166	86,383	57,743
1987	(279,294)	(4,251)	(31,981)	(27,622)	(54,745)	(114,134)	(46,561)
1988	(246,515)	(5,556)	(23,187)	(28,430)	(64,371)	(80,478)	(44,493)
1989	(425,999)	(6,600)	(44,018)	(26,648)	(70,615)	(123,513)	(154,605)
1990	(528,146)	(11,095)	(54,520)	(51,264)	(112,009)	(160,290)	(138,969)
1991	(222,630)	9,241	(13,136)	6,229	(35,609)	(80,573)	(108,782)
1992	(285,765)	(6,192)	(26,409)	(40,900)	(47,433)	(84,007)	(80,824)
1993	(37,731)	(12,736)	16,625	11,264	44,936	59,526	(157,346)
1994	132,115	20,522	(18,141)	(5,976)	(16,959)	(66,326)	218,996
1995	288,434	2,104	63,967	22,977	52,284	94,556	52,546
1996	100,698	10,721	10,012	(9,183)	57,853	7,972	23,323
1997	(20,027)	(1,815)	(3,137)	18,156	23,597	66,033	(122,861)
1998	436,864	6,773	46,658	47,028	96,685	108,054	131,666
1999	(244,561)	(3,091)	(40,132)	(33,040)	(60,543)	(8,967)	(98,788)
Total:	(684,571)	(4,951)	(62,855)	(58,504)	(104,510)	(132,152)	(321,599)
19-Year Average:	(36,030)	(261)	(3,308)	(3,079)	(5,501)	(6,955)	(16,926)

Year is defined as Spring of each year, based on DWR annual water level contour maps. Although the base period is from 1981 to 1999 (19 years), the 19-year average presented above considers the annual change in storage from 1981 to 1982 as the first year of calculated storage change.

As indicated in Table 16, using the specific yield method, there was a water supply deficiency of about 684,600 af over the 19-year base period, or approximately 36,000 afy. Most of the water supply deficiency, some 321,600 af (or about 16,900 afy), occurred in Hydrologic Unit No. VI. For the most part and given the accuracy of the estimates, Hydrologic Unit Nos. II through V show a slight deficit of from about 3,000 to 7,000 afy. Hydrologic Unit No. I shows a slight water supply deficit over the base period.

Table 17. Estimated Total Groundwater in Storage for 1951, 1971, 1981, 1995, and 1999
(in acre-feet)

Year	Specific Yield	Total Groundwater in Storage						
		Entire District	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI
1952	6%	17,048,154	469,070	1,927,361	1,508,871	3,098,639	4,445,917	5,598,297
1971		16,753,196	472,353	1,867,082	1,474,167	3,115,848	4,437,702	5,386,043
1981		17,016,747	473,214	1,881,016	1,491,498	3,181,823	4,502,980	5,486,216
1995		16,292,613	462,203	1,780,298	1,424,475	3,020,105	4,280,456	5,325,076
1999		16,788,413	473,027	1,866,577	1,476,323	3,161,054	4,438,768	5,372,665
1952	8%	22,730,874	625,427	2,569,815	2,011,828	4,131,519	5,927,889	7,464,395
1971		22,337,592	629,805	2,489,442	1,965,556	4,154,464	5,916,936	7,181,390
1981		22,688,995	630,952	2,508,021	1,988,664	4,242,431	6,003,973	7,314,955
1995		21,723,484	616,271	2,373,730	1,899,301	4,026,807	5,707,275	7,100,101
1999		22,384,553	630,702	2,488,769	1,968,431	4,214,739	5,918,357	7,163,554
1952	10%	28,413,592	781,783	3,212,269	2,514,785	5,164,399	7,409,862	9,330,494
1971		27,921,991	787,256	3,111,803	2,456,945	5,193,080	7,396,170	8,976,737
1981		28,361,245	788,690	3,135,026	2,485,829	5,303,039	7,504,966	9,143,693
1995		27,154,354	770,338	2,967,163	2,374,126	5,033,509	7,134,093	8,875,127
1999		27,899,558	788,378	3,110,961	2,460,539	5,268,424	7,397,946	8,954,443

Plates 42 through 48 - Cumulative Annual Change in Storage, present graphical depictions of the estimated annual storage changes together with the cumulative changes in storage. It should be noted that for the approximate 340,000-acre District, the base period deficit of approximately 684,600 af represents an average drop in water level of about 25 feet. For Hydrologic Unit Nos. I through V, where the range of deficiency is from about 100 to almost 7,000 afy, the average water level declines are from zero to up to 10 feet (Hydrologic Unit V). Most of the water level declines have occurred in Hydrologic Unit No. VI and locally as much as 90 feet over the 19-year base period. The magnitude of the historical water level variations (and changes) in the District is, in some cases, quite pronounced, as can be seen on Plates 26 through 31.

Using an average District-wide specific yield value of 8 percent for all sediments to the base of permeable sediments, there was approximately 304,000 af less groundwater in storage in the District in 1999 compared to 1981, or an approximate 1 percent decrease in total groundwater in storage over the base period. If an "average" specific yield value of 10 percent is used, the storage depletion is on the order of 400,000 af, and is more consistent with the data provided in Table 16. The magnitude and distribution of the change in storage is reflected in changes in water levels for this period as shown on Plate 39 - Contours of Equal Difference in Water Levels, 1981-1999. The greatest change in water levels for this comparative period was in Unit VI, where declines in water levels on the order of 90 feet have locally occurred. The reduction in the amount of groundwater in storage in the District overall for the base period is viewed as an indication of overdraft. However, as indicated on Plate 39, not all areas of the District experienced similar trends in water levels or changes in storage. Clearly, some areas have experienced significantly decreased (Hydrologic Unit No. VI) or minimal (Hydrologic Units Nos. I to IV) changes of groundwater in storage. Comparison of storage conditions in 1981 to 1995 or from 1952 to 1999, Plates 40 and 41, gives an indication of the magnitude of groundwater storage changes from relatively high District-wide water level conditions to District-wide low water level conditions and, in the latter example, over an approximate 50-year period. The 1995 period, based on inspection of long-term hydrograph records throughout the District, would appear to represent District-wide historical low water levels (mid 1990s). For the 1952 to 1995 and 1981 to 1995 periods, the storage change for the entire District is on the order of 1,000,000 af (using an average specific yield of 8 percent). As Terminus Dam was not in operation until 1961, the former period did not have the benefit of regulation of surface flow from the Kaweah River and other sources for the entire period.

There are uncertainties in the water level contours and in the interpretation of the water level data. This is particularly true in the western part of District where both confined and unconfined conditions occur. The influence of a particular data point on the regional piezometric surface is based in large part on the density of available data points. If more data points were available in certain areas, the contours could change. A groundwater high or depression that is not contoured (because there are no available data points) will only introduce error if it is present either at the beginning or ending of the period being compared (i.e., is not present both at the beginning and ending of the comparison period). Similarly, the magnitude of the storage change in the District is also governed by the specific yield value selected. An average value of 8 percent for the entire District is considered appropriate and consistent with Davis (1957).

3.5 SUBSURFACE FLOW

3.5.1 Background

Subsurface groundwater flow occurs across the District boundaries and hydrologic units in accordance with the hydraulic gradient and permeability of the materials. Estimates of the average quantities of such flow were provided by B&E (1972) for a uniform hydraulic gradient for their 5-year base period using "average" hydraulic conductivity or permeability values for the principal aquifer units. The reaches or cross sectional areas across which such flow occurred are shown on Plate 6 of the B&E report (included as Appendix B) and indicate average volumes of subsurface flow from zero (in Hydrologic Unit No. I) to 45,000 afy (from Hydrologic Unit Nos. V to VI). The estimates of subsurface flow were then used by B&E as part of the hydrologic budget to evaluate water supply surplus and deficiencies within the District.

Although not explicitly stated by B&E (1972), estimates of subsurface flow within the District must be considered a gross approximation due to the inherent variability in aquifer properties, the complexity of the gradients, and the somewhat arbitrary nature of the aquifer cross-sectional areas. As discussed by B&E, unconfined groundwater moves in response to the slope of its surface, and the direction of flow is perpendicular to the contour lines shown on groundwater level contour maps. The rate of flow is a function of the slope of the groundwater surface and the permeability of the water-bearing materials. Rates of flow on the order of a few feet per day are common, although in materials of low permeability, such rates may be reduced to on the order of a few feet per year. Flow of groundwater in confined aquifers is analogous to the flow of water in a pressure conduit. Groundwater movement is induced as a result of head differentials created by pumping extractions from the confined aquifer or by a buildup in the water table in the unconfined groundwater body supplying the aquifer.

Examination of Plates 32 through 38 shows the general direction of groundwater flow in the various aquifer systems within the District and where subsurface inflow occurs both to and from the District in these systems. A discussion of the general flow patterns over the base period has been provided in Table 15. The principal direction of groundwater flow is to the southwest parallel to the major axis of the District. Unconfined groundwater in the Kaweah River alluvial fan and continental deposits moves in this direction through Hydrologic Unit Nos. I to V as shown on the plates as a typical lobe of recharge.

Outflow of groundwater from the District occurs in the Kaweah River alluvial fan deposits in Hydrologic Unit No. IV toward the pumping depression north of Exeter. Groundwater outflow also occurs to the west in the confined aquifer system below the Corcoran Clay in Hydrologic Unit No. VI. Subsurface inflow to the District occurs in the confined aquifer system above the Corcoran Clay in Hydrologic Unit No. IV, and Hydrologic Unit No. V from the Tule River system to the south.

The influence of water supply from the Kings River also occurs to lands generally west of the District and can be seen by contours that reflect replenishment by the distributaries in these hydrologic units. They also show the pumping depressions, which have been created in Hydrologic Unit No. VI north of Corcoran and, to a lesser extent, west of Visalia.

3.6 METHOD OF ANALYSIS

For purposes of analyses of water supply and use during the 19-year base period, quantitative estimates of subsurface flow between the hydrologic units and inflow to and outflow from the District were performed using the standard D'Arcy equation of flow. In this method, the rate of groundwater flow is expressed by the equation $Q = PIA$, where P is the coefficient of aquifer permeability (horizontal hydraulic conductivity), I is the average hydraulic gradient, and A is the cross-sectional area of the saturated aquifer. Permeability data for the aquifers in the District have been discussed earlier in this chapter. B&E (1972) estimated average horizontal hydraulic conductivity values for the main aquifer units in the District from pump test data, using empirical relationships between well production, drawdown and transmissibility developed by the U.S. Geological Survey (Croft and Gordon, 1968). Aquifer cross-sectional profiles were presented in Chapter 2 of this report. Water level data and hydraulic gradients at the boundaries of the District and across representative reaches of the hydrologic units are available, in GIS, from the water level contour maps for each year of the base period. The GIS database automated the calculations of the variable hydraulic gradients for each year of the base period across 25 reaches where the direction(s) of groundwater flow were more or less uniform over the 19-year base period. A program was then written that automatically calculated the annual volumes of underflow across each reach. A typical map showing the subsurface reaches and magnitudes of flow (in afy) for the Spring 1999 water level data are shown on Plate 49 - Typical Map of Subsurface Flow Calculation. A summary of the subsurface flow estimates both from the District and for each hydrogeologic unit during the 19-year base period is presented on Table 18 - Summary of Subsurface Groundwater Flow Calculations.

The data in Table 18 indicate that for the entire District, over the base period, there was an average annual net inflow across (into) District perimeter boundaries of about 30,700 af. Inflow was about 12,000 afy into Hydrologic Unit No. 1 and about the same magnitude into Unit VI. Seasonal outflows occurred from Hydrologic Unit No. IV (southeast of the District) during periods of maximum storage or periods of District-wide replenishment during the early 1980s and late 1990s. Inflows across the District boundaries over the base period averaged about 55,600 afy, while outflows averaged about 24,900 afy. Table 19 - Hydrologic Unit Subsurface Inflow and Outflow Volumes, presents net inflow and outflow volumes for each unit for each year of the base period.

Comparison of the subsurface groundwater flow volumes shown in Table 19 to those calculated by B&E (1972, page VI-10 and Plate 6) is of interest. The hydrologic unit boundaries are for the most part substantially different, although some reaches are similar. The volumes of annual subsurface underflow, however, fall within the same general magnitudes.

3.7 SUBSIDENCE

Study of the causes of subsidence and the mechanics of aquifer system responses to fluid withdrawals has been the subject of considerable research in California, largely due to the pioneer efforts of Dr. Joseph Poland. Association of Engineering Geologists (AEG) Special Publication No. 8 (1998) provides a wealth of information on subsidence in California caused by groundwater withdrawal. Briefly, under the principal of effective stress, compaction of a sequence of interbedded aquifers and aquitards can occur only as rapidly as pore pressures throughout the sequence can reach equilibrium as pressure is reduced in the pumped aquifer. In aquitard deposits (clay and silt beds) such as those that exist in the District west of U.S. Highway 99, which have a high porosity and a very low permeability, the drainage required to reach equilibrium (i.e., maximum consolidation) can be a very slow process, often requiring years.

Unconsolidated confined aquifers (and aquitards) even at great depth are highly sensitive to changes in effective stress. Even small stress changes may cause permanent, widespread compaction. Pumping drawdown is a direct measure of effective stress changes that will occur in the aquifer system. Depending on the type of aquifer being stressed, compaction may be either recoverable (if the aquifer system responds elastically) or largely irrecoverable (if the aquitard deposits respond inelastically).

Table 18. Summary of Subsurface Groundwater Flow Calculations

(in 1,000s of acre-feet)

Year	Hydrologic Unit I				Hydrologic Unit II			Hydrologic Unit III		Hydrologic Unit IV			Hydrologic Unit V		Hydrologic Unit VI	Entire District Boundary		
	Boundary	To Unit No. II	To Unit No. III	To Unit No. IV	Boundary	To Unit No. III	To Unit No. VI	To Unit No. V	To Unit No. VI	Boundary	To Unit No. III	To Unit No. V	Boundary	To Unit No. VI	Boundary	Inflow	Outflow	**Net**
1981	10.7	5.4	2.3	7.4	0.1	5.6	0.4	(2.4)	1.6	(20.3)	8.4	20.4	8.9	13.9	28.0	73.6	(46.2)	**27.4**
1982	6.2	5.4	2.8	14.0	(1.3)	7.2	7.2	0.8	8.6	(5.7)	10.7	16.3	6.2	12.4	27.0	64.5	(32.2)	**32.4**
1983	13.5	4.6	2.7	7.6	(0.3)	7.1	2.2	(5.2)	4.5	(20.8)	8.5	13.3	5.9	23.1	14.7	61.8	(48.9)	**13.0**
1984	8.3	4.4	1.7	5.7	(3.1)	12.7	1.4	(8.4)	5.2	28.3	10.9	5.5	1.1	11.1	13.6	87.0	(38.7)	**48.2**
1985	8.4	6.2	1.4	3.1	0.4	3.2	1.2	(4.6)	2.4	16.9	6.2	10.8	0.4	17.8	4.9	47.1	(16.1)	**31.0**
1986	2.8	6.6	2.5	9.5	(7.2)	7.0	4.3	(3.9)	0.7	10.2	6.9	2.4	1.0	15.4	13.6	45.1	(24.8)	**20.4**
1987	14.9	5.2	3.1	13.6	(1.0)	0.7	3.1	(4.1)	2.4	23.6	6.3	11.4	(2.5)	15.2	10.5	54.3	(8.8)	**45.5**
1988	18.6	5.7	2.4	7.0	(1.2)	2.6	2.0	3.7	4.6	0.1	4.4	15.0	0.8	5.1	5.1	35.9	(12.5)	**23.4**
1989	5.3	3.9	2.4	7.1	4.5	6.4	1.4	5.0	(1.0)	(11.9)	6.6	6.5	5.8	5.8	10.1	36.8	(23.0)	**13.8**
1990	18.2	4.5	2.1	9.8	0.8	3.0	0.5	4.3	5.0	2.4	7.7	6.2	3.7	4.6	16.5	53.5	(11.9)	**41.6**
1991	9.6	6.0	2.2	12.9	4.2	5.4	0.5	7.9	(0.4)	(3.3)	4.0	10.8	4.5	4.6	26.9	59.9	(18.1)	**41.8**
1992	13.6	5.7	4.5	16.1	2.8	(2.3)	1.5	10.5	2.7	23.9	3.3	13.7	6.5	2.6	6.8	62.9	(9.3)	**53.6**
1993	5.6	6.4	5.2	14.0	2.8	2.3	5.8	3.5	4.7	13.8	5.9	13.5	0.9	8.1	11.2	48.1	(13.8)	**34.3**
1994	6.0	6.0	4.7	15.9	7.2	0.9	0.2	7.1	3.1	7.2	3.6	18.8	1.1	13.5	1.8	36.6	(13.3)	**23.3**
1995	12.4	13.3	3.4	10.6	8.6	(1.4)	1.8	5.9	4.7	(4.3)	4.0	16.2	10.1	8.9	20.6	59.8	(12.4)	**47.4**
1996	26.3	3.8	3.7	5.5	1.5	8.0	3.7	0.1	8.5	(11.0)	5.5	7.4	5.3	5.3	14.3	71.5	(35.1)	**36.4**
1997	18.6	11.6	3.5	13.3	0.8	14.9	0.6	0.4	5.7	(18.8)	15.3	5.6	0.6	5.4	16.7	68.6	(50.7)	**17.9**
1998	16.1	8.2	4.4	10.5	3.4	4.7	2.5	(1.9)	5.0	14.1	10.9	17.4	(3.0)	13.8	(6.3)	49.2	(24.9)	**24.3**
1999	15.7	7.2	2.1	5.7	0.6	3.6	0.5	(0.8)	5.5	(3.1)	6.9	23.3	3.2	13.3	(9.2)	39.5	(32.4)	**7.2**
Avg.	12.1	6.3	3.0	10.0	1.2	4.8	2.1	0.9	3.9	2.2	7.2	12.3	3.2	10.5	11.9	55.6	(24.9)	**30.7**

Note: Numbers in parentheses denote flow either from a District boundary or from a hydrologic unit.

Table 19. Hydrologic Unit Subsurface Inflow and Outflow Volumes
(in 1,000s of acre-feet)

Year	Hydrologic Unit No. I			Hydrologic Unit No. II			Hydrologic Unit No. III			Hydrologic Unit No. IV			Hydrologic Unit No. V			Hydrologic Unit No. VI			Entire District Boundary		
	Inflow	Outflow	**Net**	Inflow	Outflow	**Net**	Inflow	Outflow	**Net**	Inflow	Outflow	**Net**	Inflow	Outflow	**Net**	Inflow	Outflow	**Net**	Inflow	Outflow	**Net**
1981	13.2	17.7	**(4.5)**	9.5	10.0	**(0.5)**	18.7	1.6	**17.1**	26.7	68.4	**(41.7)**	29.3	16.3	**13.0**	43.9	0.0	**43.9**	73.6	46.2	**27.4**
1982	11.9	27.8	**(15.9)**	7.7	18.0	**(10.3)**	20.7	9.3	**11.4**	33.6	52.2	**(18.6)**	25.5	14.6	**10.9**	55.1	0.0	**55.1**	64.5	32.2	**32.4**
1983	13.5	14.8	**(1.3)**	7.3	12.3	**(5.0)**	23.5	4.5	**19.0**	38.2	73.2	**(35.0)**	24.8	33.9	**(9.1)**	44.5	0.0	**44.5**	61.8	48.9	**13.0**
1984	11.7	15.3	**(3.6)**	7.7	20.6	**(12.9)**	33.7	5.2	**28.5**	74.1	56.5	**17.6**	22.5	35.3	**(12.8)**	31.3	0.0	**31.3**	87.0	38.7	**48.2**
1985	8.8	11.1	**(2.3)**	10.4	8.2	**2.2**	15.3	2.4	**12.9**	36.2	33.2	**3.0**	15.5	26.7	**(11.2)**	26.3	0.1	**26.2**	47.1	16.1	**31.0**
1986	11.4	27.1	**(15.7)**	6.6	18.6	**(12.0)**	20.4	0.7	**19.7**	39.3	29.0	**10.3**	15.4	31.3	**(15.9)**	34.9	0.8	**34.1**	45.1	24.8	**20.4**
1987	18.0	25.0	**(7.0)**	7.4	7.0	**0.4**	14.1	2.4	**11.7**	39.9	20.4	**19.5**	14.1	24.4	**(10.3)**	31.1	0.0	**31.1**	54.3	8.8	**45.5**
1988	18.9	15.4	**3.5**	9.6	9.8	**(0.2)**	9.4	8.3	**1.1**	14.2	26.5	**(12.3)**	19.5	5.1	**14.4**	16.8	0.0	**16.8**	35.9	12.5	**23.4**
1989	15.3	23.3	**(8.0)**	9.5	8.9	**0.6**	16.4	5.0	**11.4**	7.9	25.9	**(18.0)**	18.1	6.7	**11.4**	17.3	1.0	**16.3**	36.8	23.0	**13.8**
1990	20.5	18.7	**1.8**	9.3	7.5	**1.8**	12.9	9.2	**3.7**	21.1	22.8	**(1.7)**	17.5	7.8	**9.7**	26.5	0.0	**26.5**	53.5	11.9	**41.6**
1991	17.2	28.8	**(11.6)**	10.4	6.1	**4.3**	12.1	7.9	**4.2**	21.7	26.9	**(5.2)**	25.2	6.5	**18.7**	32.0	0.4	**31.6**	59.9	18.1	**41.8**
1992	22.4	35.1	**(12.7)**	11.4	2.0	**9.4**	7.8	15.5	**(7.7)**	40.0	17.0	**23.0**	30.6	2.6	**28.0**	13.6	0.0	**13.6**	62.9	9.3	**53.6**
1993	12.7	32.7	**(20.0)**	10.6	9.6	**1.0**	13.4	8.2	**5.2**	34.9	26.5	**8.4**	20.1	10.2	**9.9**	30.0	0.3	**29.7**	48.1	13.8	**34.3**
1994	8.6	29.2	**(20.6)**	13.2	1.1	**12.1**	9.2	10.2	**(1.0)**	26.9	26.0	**0.9**	31.5	17.9	**13.6**	21.8	3.3	**18.5**	36.6	13.3	**23.3**
1995	15.7	30.6	**(14.9)**	23.3	1.8	**21.5**	7.4	12.0	**(4.6)**	15.9	29.8	**(13.9)**	32.6	9.3	**23.3**	36.0	0.0	**36.0**	59.8	12.4	**47.4**
1996	26.8	13.5	**13.3**	6.3	12.8	**(6.5)**	17.1	8.6	**8.5**	31.8	50.2	**(18.4)**	17.0	9.6	**7.4**	32.4	0.5	**31.9**	71.5	35.1	**36.4**
1997	18.9	28.8	**(9.9)**	14.3	17.5	**(3.2)**	33.8	6.1	**27.7**	44.5	71.0	**(26.5)**	9.8	8.5	**1.3**	28.4	0.0	**28.4**	68.6	50.7	**17.9**
1998	16.5	23.5	**(7.0)**	13.1	8.7	**4.4**	21.9	5.0	**16.9**	40.5	44.2	**(3.7)**	22.2	23.4	**(1.2)**	22.0	7.0	**15.0**	49.2	24.9	**24.3**
1999	15.7	14.9	**0.8**	10.9	7.3	**3.6**	13.3	5.5	**7.8**	20.1	47.7	**(27.6)**	29.8	17.4	**12.4**	22.0	11.9	**10.1**	39.5	32.4	**7.2**
Avg.	15.7	22.8	**(7.1)**	10.4	9.9	**0.6**	16.9	6.7	**10.2**	32.0	39.3	**(7.4)**	22.2	16.2	**6.0**	29.8	1.3	**28.5**	55.6	24.9	**30.7**

Note: Numbers in parentheses denote flow either from a District boundary or from a hydrologic unit.

During the first cycle of groundwater withdrawal, most of the pumped water comes from the unrecoverable compaction of the aquifer system. During subsequent cycles of water level declines or to the extent that groundwater withdrawals result in water level declines greater than the historical range, the aquifer system preconsolidation stresses again are exceeded, resulting in renewed compaction and subsidence.

B&E (1972) commented very briefly on subsidence in their report, stating "a substantial portion of the District west of Highway 99 has experienced land subsidence of up to 2 feet since 1962 and over 5 feet since 1948." No reference was provided as to the source of this historic subsidence but B&E did comment that the subsidence was "deep subsidence." Data control in Ireland et al. (1984) indicates that land subsidence from 1926 to 1970 in the District has likely been no more than several feet and restricted to the extreme west side of the District (Hydrologic Unit No. VI). Subsequent work by Swanson, 1998 in Borchers (1998) indicate that with the availability of new surface water supplies in the San Joaquin Valley in about 1970, rates of subsidence were substantially reduced. From 1925 to 1995, such subsidence occurred only in drought years and in local areas where historic low water levels were exceeded.

In the District, there is some evidence in the hydrologic records contained in the Task 3 Interim Report that historic low water levels were exceeded in some local areas in the early to mid-1990s. The duration of such exceedances were confined to a year or so and the transient nature of the exceedances were likely insufficient to create renewed aquitard drainage and significant additional subsidence. Such additional subsidence and loss of groundwater storage space is not considered material to the water balance. Moreover, the magnitude of documented subsidences in the District is relatively small, on the order of several feet, and localized.

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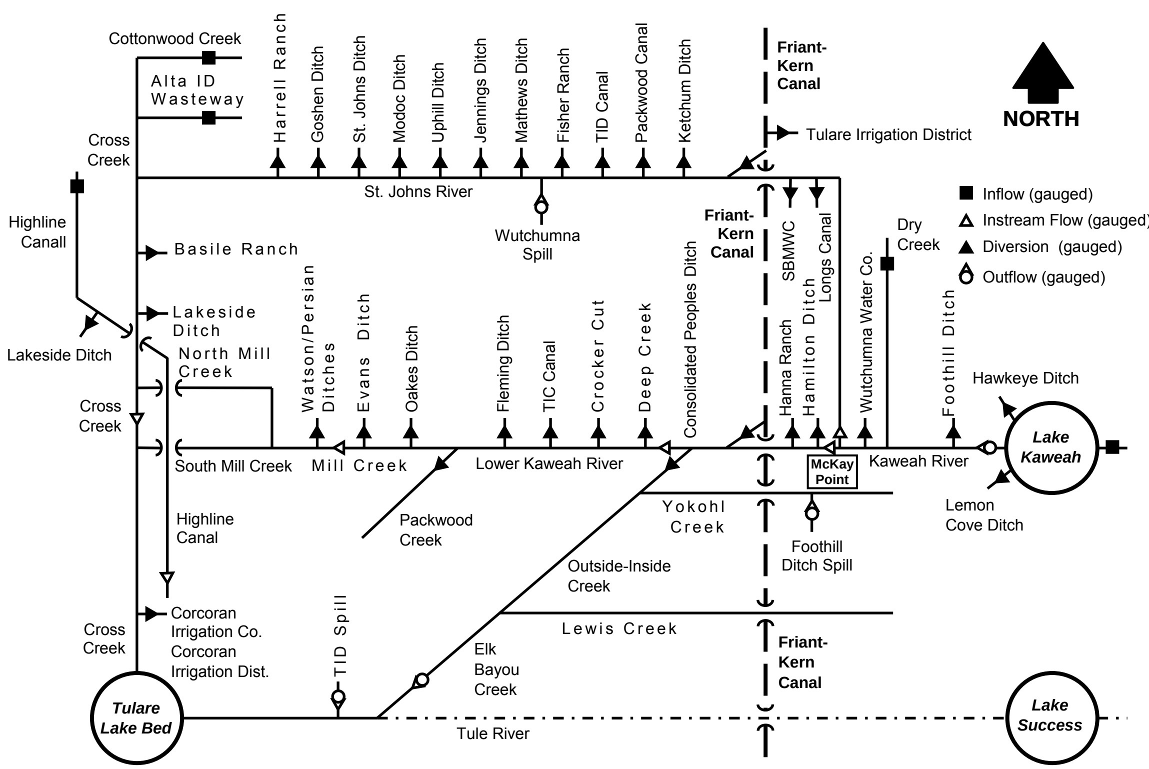
CHAPTER 4 - SURFACE WATER

4.1 INTRODUCTION

Presented in this chapter is the tabulation and analysis of the availability, conveyance, and delivery of surface water in the District (both locally derived and imported sources), as well as a rationale to apportion the delivery of such surface water to the entitlement holders within each of the six hydrologic units during each year of the base period. Also evaluated is accounting for the conveyance losses of such deliveries in the reaches and segments of the rivers, canals, and ditches and the compilation and tabulation of artificial recharge activities ("sinking basins") in the District. The latter two items form components of inflow in the water balance equation.

The Kaweah River System Schematic (see Figure 2) was prepared with the assistance of District staff (Mr. Larry Dotson) and Mr. Dennis Keller. The schematic was, in turn, compiled in GIS and used with monthly inflow and instream flow data to apportion surface water deliveries, conveyance losses, and artificial recharge. This information is, in part, contained on Plate 50 - Destination of Deliveries of Surface Water. Plate 3 - Entitlement Holder Service Area Map, delineates the boundaries of surface water of entitlement holders in the District. The methods of analysis are described more fully in the text and tables that follow. Monthly surface water flow data for the District dating from 1970 to 2000 (water level data) were provided in the Task 4 Interim Report and are not reproduced here.



Note: *Jennings Ditch point of diversion abandoned in 1978. Jennings Ditch water diverted through Modoc and/or Goshen Ditches from 1974 to current.*

Figure 2. Kaweah River System Schematic - Surface Water Diversion and Delivery

4.2 PRESENTATION OF THE DATA

To facilitate an understanding of the manner in which surface water (both locally derived and imported) is distributed in the natural and constructed channels in the District, the following discussion is provided. The natural channels are the streams, rivers and creeks that carry runoff from the catchments in the Sierra Nevada Mountains and foothill regions along the eastern side of the District. The constructed channels are a system of hydraulically inter-connected canals and channels that import surface water into the District, divert it for delivery to the entitlement holders, and distribute it to individual land units within each of the six hydrologic units. Some natural channels receive diversions of imported surface water and divert it to other diversion channels, or deliver it to other entitlement holders.

In this chapter, we describe the record data of surface water in the Kaweah River system and from imported sources, the seepage losses associated with these flows (based on watermaster gauge and diversion records), and the riparian uses (diversions) that occur on the natural systems. In turn, records of headgate diversions are similarly discussed in a sequential fashion as surface water is diverted into constructed canals and channels for delivery to entitlement holders for farm delivery. Such headgate diversions, in turn, experience seepage (system) losses, can be redistributed to artificial recharge basins, or in years of very high surface water flow, leave the District as "spill" or outflow. The discussion that follows accordingly accounts for surface water from the source, provides a methodology and estimates of seepage losses in the natural and constructed canals, accounts for surface water artificially recharged, and ultimately accounts for the delivery of the remaining surface water to the agricultural lands in each hydrologic unit. A schematic of this descriptive approach is provided in Figure 3 - Surface Water Hydrology

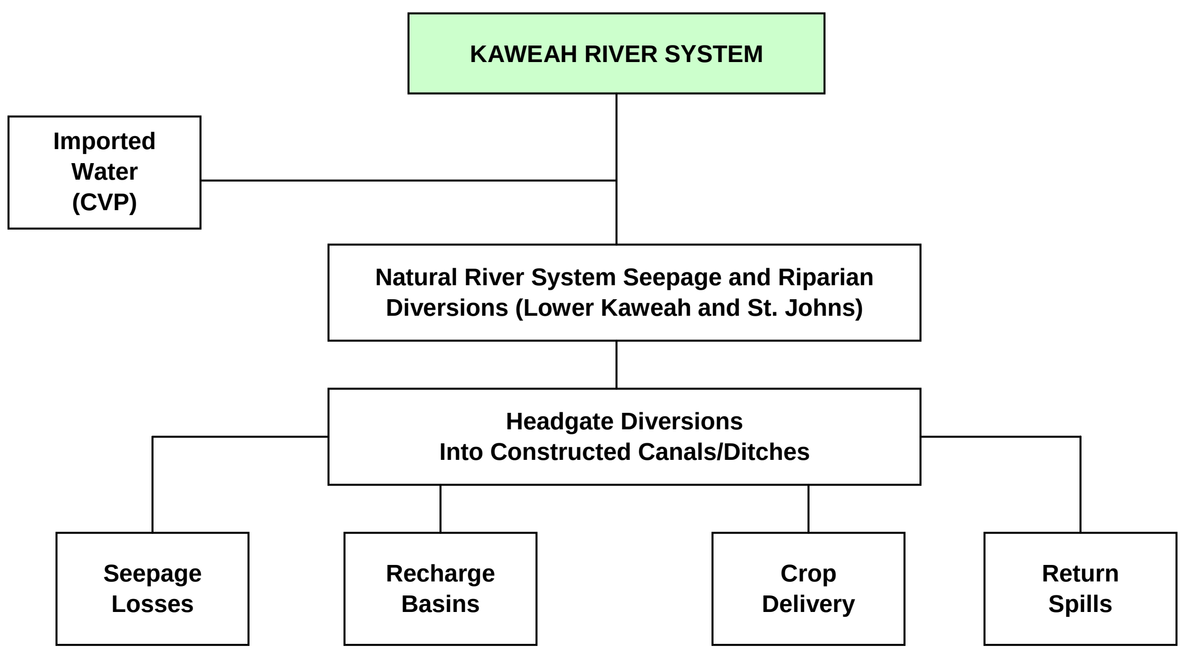


Figure 3. Surface Water Hydrology

It should be noted that limited flow data prohibit the accounting for every source and diversion in the District.

4.3 SUMMARY OF AVAILABLE DATA

The Kaweah and St. Johns Rivers Association accumulate data on a daily basis for the Kaweah River, Dry Creek, and Yokohl Creek. This information is tabulated on a daily basis and for the last several years has been compiled on a computer-driven database. Annual reports are published by the Association, which are currently in the process of being brought current.

The records of the stream groups impacting the facilities and stockholders of the Consolidated Peoples Ditch Company and the other companies that they manage are in a hit and miss fashion. Substantial data gaps exist; however, in the overall analysis, the data gaps represent relatively small quantities of contributory flows. The records of the USGS are, for the most part, supplemental to the records of the Association and the Consolidated Peoples Ditch Company. The information that is published by the USGS, however, does fill some of the data gaps that exist in the information related to the local stream groups.

Supplemental sources of water supply have been imported to the District since its inception. Deliveries to lands that eventually became a part of the District started in the late 1800s and were made available from the Kings River. An additional source of supplemental supply was made available to lands located within the District in the early 1950s. The source of these supplies was from the CVP and took the form of both long-term contract supplies and short-term contract supplies. With the advent of the termination of short-term contracting procedures, supplemental supplies, in addition to the long-term CVP supplies, have been made available through the vehicle of temporary contracts.

Supplies made available from the Kings River impact the north, northwestern, and westerly areas of the District. Information as to the gross deliveries made available to these areas is available from the Kings River Water Association. The watermaster of the Kings River Water Association publishes an annual report that contains the information necessary to document the gross delivery information. Specific information related to deliveries into areas in and adjacent to the District on the north, northwest, and westerly boundaries are available from records of the Alta Irrigation District, the Corcoran Irrigation Company, the Corcoran Irrigation District, the Kings County Water District, the Lakeside Irrigation Water District, and the Melga Water District.

Deliveries of CVP supplies into areas in and surrounding the District are summarized in annual reports published by the U.S. Bureau of Reclamation. Principal deliveries of CVP water into the District have been related to the short-term contract previously held by the District and the long-term CVP contract held by the TID. The records of the U.S. Bureau of Reclamation document the specific deliveries into the District and into the TID, and parallel documenting records are available from each entity. The pricing structure of CVP supplies has and is further anticipated to impact deliveries into the TID. Studies indicating the decline of the average annual deliveries from the historic 108,000 af to a potential low-average of 60,000 af are available in the public domain.

The District is impacted by CVP deliveries to districts surrounding the District, as well as to the City of Visalia. Records of these deliveries are available from the U.S. Bureau of Reclamation on a gross annual diversion basis with specific information available to document deliveries to specific lands that overlap the boundaries of the CVP contracting entities with the boundaries of the District and adjacent thereto. These contracting districts include the Exeter Irrigation District, the Ivanhoe Irrigation District, the Lewis Creek Water District, the Lindmore Irrigation District, the Lindsay-Strathmore Irrigation District, and the Lower Tule River Irrigation District.

State Water Project delivery information is available on a gross basis from the DWR. Specific delivery information to lands adjacent to the District is available from the Tulare Lake Basin Water Storage District. Through cooperation with entities in and adjacent to the District, information related to historic transfers is likewise available.

Records exist with the District and with the U.S. Bureau of Reclamation relative to contract and temporary purchases of supplemental surface water by the District and by non-CVP entities located within the District. On a like data available basis, the description of the exchange programs of the City of Visalia and the quantities delivered under those exchange programs are available.

4.4 WATER REQUIREMENTS

Water is used in the District primarily to satisfy the demands of irrigated agriculture, which constitutes about 90 percent of total water use. The remaining 10 percent is used to supply municipal, industrial, and related demands. Water applied to irrigated crops for the most part is consumptively used through evaporation and transpiration. Irrigation water in excess of consumptive use penetrates beyond the crop root zone to eventually return to groundwater storage. Of the total water applied for irrigation, about 75 percent is consumptively used. The relationship between consumptive use of irrigation water and total irrigation application expressed as a percentage is termed "irrigation efficiency." Irrigation efficiency varies with the irrigation practices of the individual operation, crop, and soil type.

Similarly, of the water used for municipal and industrial purposes, part is consumptively used and, in part, returns to groundwater storage through deep penetration from irrigation of lawns and other vegetation, or is discharged through municipal sewerage facilities. In the District, sewage from urbanized areas is discharged to ponds, where it is either evaporated, returns to groundwater storage by artificial recharge activities, or is applied to adjacent agricultural lands.

Precipitation on District lands is largely consumptively used. The occurrence of runoff of direct precipitation, which would enter surface channels and escape beyond the boundaries of the District, is very infrequent, but does occur. Since both direct precipitation and applied water in excess of consumptive use return to groundwater storage for eventual reuse, the measure of net water requirement in the District is consumptive use. A detailed designation of land use classification, consumptive use, and gross required irrigation demand in the District is provided in Chapter 6 of this Final report.

B&E (1972) estimated that about 930,000 afy of irrigation water was required to meet the consumptive use of crops in the District (conditions prevalent in about 1965). At that time, approximately 256,000 acres of land in the District were irrigated and an average consumptive use of 3.6 af per acre per year on average was used to determine the irrigation demand. As is more fully discussed in Chapter 6, over the 1981 to 1999 base period, there was an average of about 270,000 acres of irrigated land in the District, with an average crop demand of 809,000 afy, or about 3.0 af per acre per year. The decline in crop unit water use values reflects an overall change in crop types and irrigation practices (greater efficiency).

On average, for the 1981 to 1999 base period, it is estimated that about 251,000 af of water was diverted from surface sources for crop irrigation after consideration of seepage losses associated with the deliveries. ~~Imported water, or surface water distinct from the Kaweah River system (both CVP and Kings River water), averaged some 73,000 afy.~~ The balance of the gross irrigation demand, or some 558,000 afy, was extracted from the groundwater reservoir. Conveyance loss related to the delivery of surface water is significant, and the estimated annual quantity of such a loss is described in this chapter.

4.5 KAWEAH RIVER WATER

The Kaweah River rises in the Sierra Nevada at an elevation of over 12,000 feet and drains a watershed area of about 630 square miles above the foothill line. Terminus Reservoir, located about 3-1/2 miles east of the easterly District boundary, has a tributary drainage area of about 560 square miles, which produces about 95 percent of the total runoff of the watershed. Dry (Limekiln) Creek and Yokohl Creek are tributaries entering the Kaweah River below Terminus Reservoir and produce significant quantities of water only during flood periods.

Runoff in Kaweah River is largely retained within the District and only in infrequent years of exceptionally large runoff is there escape to Tulare Lake bed. Since completion of Terminus Dam and Reservoir in 1961, seasonal storage of Kaweah River flows has been provided, which assists in regulation to irrigation demand schedules. Other than maintenance of a minimum pool for recreation, no carryover storage is provided in the reservoir.

At McKay Point, about 1/2 mile east of the easterly District boundary, the Kaweah River divides into the St. Johns River and Lower Kaweah River branches (refer to Figure 2). Water is diverted from the St. Johns and Lower Kaweah rivers and distributed through a complex system of natural channels and canals owned or operated by numerous agencies and entitlement holders within the District, all of which have established rights to the use of water from the Kaweah River.

Runoff of the Kaweah River has been continuously measured since 1903 at gauging stations near Three Rivers, located about 10 miles upstream from the easterly boundary of the District. Much of these runoff records analyzed in the Task 1 Interim Report related to the selection of the base period. Completion of Terminus Dam and Reservoir in 1961 required the relocation of an existing gauging station, and the establishment of two new upstream stations: 1) Kaweah River at Three Rivers, and 2) South Fork of Kaweah River near Three Rivers. The annual totals of measured flows at these two sites after 1961 continue the long-term record of Kaweah River near Three Rivers.

During the period of record from Water Year 1903-04 through 1999-2000, the average annual runoff was 432,928 af, ranging from a minimum of 93,400 af in 1976-77 to a maximum of 1,402,000 af in 1982-83. Records of the annual runoff of Kaweah River near Three Rivers during the period are provided in Table 20 - Annual Runoff of Kaweah River Near Three Rivers for Period 1904 through 2000.

Presented on Plate 51 - Cumulative Departure from Average Annual Runoff, is a residual mass diagram showing the accumulated annual departure from the average annual runoff of Kaweah River (near Three Rivers) during the 97-year period, expressed in percent. As shown, average runoff during the 19-year base period 1981-1999 exceeds the long-term average, being 113 percent of the 97-year period.

4.6 ST. JOHNS RIVER SYSTEM

The entitlement flow of Kaweah River at McKay Point is divided equally between the Lower Kaweah River and St. Johns River until the flow has once receded to 80 second-feet in the late summer months. Thereafter, the entire entitlement flow, regardless of the amount, is diverted into the Lower Kaweah River until such time as it first exceeds 80 second-feet after October 1. In 1945, the Wutchumna Water Company entitlement on the St. Johns River at Barton Cut (below Mathews Ditch Diversion) was transferred to the head of Wutchumna Ditch on Kaweah River above McKay Point. Thus, an additional entitlement flow, in an amount equal to the transferred Barton Cut entitlement, is diverted to the Kaweah River above McKay Point.

As shown on Figure 1, the main diversion works heading on the St. Johns River in downstream order are: Longs Canal, Sweeney Ditch, Ketchum Ditch, Packwood Canal, Tulare Irrigation District Main Canal, Mathews Ditch, Jennings Ditch, Uphill Ditch, Modoc Ditch, St. Johns Ditch, Goshen Ditch, Lakeside Ditch, and Lakelands Canal No. 2. Water is diverted from the Friant-Kern Canal to TID at a large Parshall flume and into the St. John's River immediately below the Sweeney Ditch diversion. In addition, there are several riparian users, with the principals being the Fisher & Harrell Ranch in the lower reach of the St. Johns River east of U.S. Highway 99 and Basile Ranch, west of the highway.

About 180,000 acres can receive irrigation water from the St. Johns River through facilities of 15 entities. It is estimated that on the average about 142,000 af of water per year was diverted from the St. Johns River during the base period. The average amount was about 11,000 af more than the amount estimated by B&E (1972).

4.7 LOWER KAWEAH RIVER SYSTEM

The principal diversions from the Lower Kaweah River below McKay Point in downstream order are: Hamilton Ditch, Consolidated Peoples Ditch, Deep Creek, Crocker Cut, TIC Ditch, Fleming Ditch, Packwood Creek, Oakes Ditch, Evans Ditch, and Persian and Watson

Ditch. The Hanna Ranch diversion constitutes one of the riparian uses downstream from the Hamilton Ditch diversion.

A turnout on the Friant-Kern Canal provides for releases directly into the Lower Kaweah River above Consolidated Peoples Ditch diversion point. The Ketchum Ditch, which heads on the St. Johns River, discharges into the Lower Kaweah channel below Consolidated Peoples Ditch and upstream from the Deep Creek point of diversion. Packwood Canal, which also heads on the St. Johns River, empties into the Lower Kaweah River channel below the diversion point of the Crocker Cut and upstream from the TIC Ditch diversion point. Flow of the Lower Kaweah River is measured at McKay Point (refer to Figure 1) and a gauging station is maintained below Consolidated Peoples Ditch diversion and upstream from the Deep Creek diversion. A gauging station is also maintained below the Evans Ditch diversion on Mill Creek, which is an extension of the Lower Kaweah River channel. These, and the many other points of diversion gauging stations in the District, provide the data contained in Chapter 4.

About 126,000 acres can receive irrigation water from the Lower Kaweah River system through facilities of 10 entities. On the average, an estimated 218,000 af of water per year was diverted from the Lower Kaweah River during the base period. This average amount is about 48,000 afy more than estimated by B&E (1972) for their 1961 to 1965 base period.

4.8 DISTRIBUTARIES AND CANAL SYSTEMS

As stated, the Kaweah River divides into the St. Johns and Lower Kaweah branches at McKay Point (refer to Figure 2). The St. Johns River flows northwesterly through the northern part of the District to a point approximately 2 miles east of Highway 99, where it changes course and flows in a southwesterly direction and is joined by Cottonwood Creek. Prior to reaching U.S. Highway 99 at the confluence of Cottonwood Creek, the St. Johns River becomes Cross Creek. River flows at this point are diverted into Lakeside Ditch for irrigation use by Lakeside Irrigation Water District and Lakeside Ditch Company. Corcoran Irrigation District and other Tulare Lake water users divert flows from Cross Creek into Lakelands Canal No. 2. During periods of flooding, river flows continue in the Cross Creek channel into Tulare Lake bed.

The Lower Kaweah River, below McKay Point, conveys water to a series of distributary channels and canals throughout the central and southerly portions of the District (refer to Figure 2. Outflow from the District into the Lower Kaweah River system occurs through Mill Creek to Cross Creek, through Cameron Creek in the southwestern corner of the District and from Elk Bayou to the Tule River in the southeasterly portion of the District.

The third principal conveyance system in the District is the Main Canal of the TID, which delivers Kaweah River and CVP waters for use in the TID (Hydrologic Unit No. V). Major public districts within the District serving water for irrigation are the TID, which diverts water from both the Lower Kaweah and St. Johns Rivers, and Lakeside Irrigation Water District and a portion of Corcoran Irrigation District, which receive water from the St. Johns River. Alta Irrigation District, which extends into the District on the north, receives Kings River water. However, the amount of such water entering the District is very small.

Table 20. Annual Runoff of Kaweah River Near Three Rivers for Period 1904 through 2000

Water Year	Flow (af)	Water Year	Flow (af)	Water Year	Flow (af)
1904	375,430	1937	677,233	1970	359,430
1905	345,010	1938	870,812	1971	295,221
1906	1,103,840	1939	247,186	1972	168,091
1907	599,870	1940	512,761	1973	615,606
1908	255,990	1941	641,705	1974	489,808
1909	800,851	1942	490,881	1975	383,566
1910	409,398	1943	671,294	1976	147,024
1911	546,034	1944	315,409	1977	93,372
1912	206,978	1945	550,652	1978	833,679
1913	221,095	1946	356,494	1979	417,217
1914	486,589	1947	265,189	1980	885,821
1915	370,130	1948	261,320	1981	248,274
1916	762,485	1949	218,865	1982	771,312
1917	471,092	1950	300,967	1983	1,402,011
1918	227,760	1951	421,288	1984	516,791
1919	258,800	1952	824,957	1985	329,876
1920	349,800	1953	308,116	1986	815,015
1921	347,670	1954	306,075	1987	183,861
1922	461,991	1955	276,076	1988	184,517
1923	362,674	1956	724,616	1989	214,290
1924	101,594	1957	295,056	1990	141,194
1925	325,794	1958	639,688	1991	252,289
1926	218,893	1959	154,677	1992	148,448
1927	483,935	1960	180,331	1993	550,068
1928	203,044	1961	116,769	1994	191,746
1929	222,689	1962	405,592	1995	866,684
1930	217,493	1963	491,286	1996	528,724
1931	114,214	1964	230,043	1997	759,676
1932	518,869	1965	488,004	1998	927,867
1933	283,248	1966	247,604	1999	265,999
1934	130,761	1967	1,025,228	2000	369,592
1935	357,663	1968	220,195		
1936	486,927	1969	1,271,979		
Maximum 1904-2000:	1,402,011	Maximum 1981-1999	1,402,011		
Minimum 1904-2000:	93,372	Minimum 1981-1999:	141,194		
Average 1904-2000:	432,928	Average 1981-1999:	489,402	(113% Long Term)	

Several ditch companies divert water from the Lower Kaweah River, the principal ones being Consolidated Peoples, Farmers, and Elk Bayou Ditch Companies. Mathews, Jennings, Uphill, Modoc, Goshen, and Lakeside Ditch Companies are the principal diverters from the St. Johns River. TID, Fleming, Oakes, Evans, Watson, and Persian Ditch Companies receive water from both the Lower Kaweah and St. Johns Rivers (refer to Figure 2, and on Plate 50).

Diversions of water are also made from the Kaweah River above McKay Point and conveyed through the Lemon Cove, Foothill, and Wutchumna ditches to serve approximately 10,000 acres of land outside of the boundaries of the District (refer to Figure 2).

4.9 CENTRAL VALLEY PROJECT (CVP) WATER

The U.S. Bureau of Reclamation commenced deliveries of CVP water through the Friant-Kern Canal in the latter part of 1949. TID is the only entity within the District with a long-term water service contract with the United States for CVP water. Under terms of its contract, TID receives 30,000 afy of Class 2 water, with an estimated long-term average of 97,000 afy. In addition to its contractual entitlement to CVP water, the Tulare and Corcoran Irrigation Districts, Lakeside Irrigation Water District, and the District itself have purchased water from the Bureau of Reclamation or from long-term contractors under exchange or short-term agreements during years when surplus water was available in the system. As indicated in Table 21, water purchased by the District over the base period was relatively small, some 3,360 afy on average, largely due to substantially deficient runoff and unavailability of such supplemental surface water during the 1980s.

CVP water can be diverted to the TID from three turnouts, which are located where Friant-Kern Canal crosses the Tulare Irrigation Main Canal, the St. Johns River channel, and the Lower Kaweah River channel, respectively. In addition, from time to time CVP water has been released into the Kings River channel and from there into canal systems traversing the western portion of the District.

TID accepted delivery of about 1,519,000 af of CVP water during the 19-year period from 1981 to 1999, or an average of about 82,500 afy (B&E, 1997). Table 21 provides a summary of the sources and annual volumes of imported water to the District.

4.10 TULARE IRRIGATION DISTRICT MAIN CANAL SYSTEM

The TID Main Intake Canal heads at a turnout on the Friant-Kern Canal. Diversions from Wutchumna Channel are delivered into the Main Intake Canal approximately 1/2 mile below the Friant-Kern Canal turnout. Kaweah River water for TID include a portion from the Wutchumna Ditch Company and a portion of the flow in the St. Johns.

In addition, TID diverts the major portion of its entitlement from the Lower Kaweah River through Crocker Cut and into the Main Canal. Lower Kaweah River water is also conveyed into the TID system through the Packwood Creek. The total surface water supply reaching the boundary of the TID is measured, as are flows at all of the points of diversion. Records of these measurements are available on a daily, mean monthly, and annual basis. Thus, channel conveyance losses can and have been readily determined from these records (B&E, 1997). It is estimated that, on the average, about 105,700 afy of Kaweah River water are diverted by the TID (refer to Figure 2).

4.11 KINGS RIVER WATER

Water is diverted from the Kings River by Corcoran Irrigation District and Peoples Ditch Company and conveyed through the District to lands lying generally south and west of the District's boundaries (Hydrologic Unit No. VI).

The principal conveyance facility for the Corcoran Irrigation District is the Lakelands Canal, which heads on the Kings River and runs south into the District, where is intersects Cross Creek near the Lakeside Ditch diversion. Lakelands Canal below Cross Creek is designated as the Highline Canal. Kings River entitlement water for Corcoran Irrigation District is also diverted into Lakelands Canal from Peoples Ditch through Simons Cutoff, which is located northerly of the District boundary. Conveyance losses in Lakelands Canal were estimated from recorded diversions and records of flow reaching the boundary of Corcoran Irrigation District as measured at Kansas Avenue.

In addition, Kings River water is diverted from Peoples Ditch into Melga Canal and conveyed through the portion of the District within the Lakeside Irrigation Water District. Losses in the Melga Canal within the District were estimated from recorded diversions by Peoples Ditch Company and measured flows reaching Nevada Avenue, which is coincident with the southerly boundary of the District. Volumes of Kings River water imported (and used for irrigation) in the District over the base period are relatively small, as shown in Table 21 - District Imported Water.

Table 21. District Imported Water

Calendar Year	Exeter ID[1] CVP	KDWCD CVP	Kings County WD CVP	Lakeside IWD CVP	Tulare ID CVP	Total CVP	Lakeside Kings	CIC Kings	Total Kings	Total CVP+ Kings
1981	1,073	0	8,001	0	57,164	66,238	11,117	3,836	14,953	81,191
1982	1,572	0	2,358	1,182	241,801	246,913	3,217	5,463	8,680	255,593
1983	1,626	0	0	0	75,372	76,998	0	1,463	1,463	78,461
1984	1,842	0	0	0	102,157	103,999	42,685	6,439	49,124	153,123
1985	1,187	11,445	0	12,301	69,177	94,110	3,205	4,133	7,338	101,448
1986	1,731	0	0	0	164,236	165,967	18,068	4,147	22,215	188,182
1987	881	0	0	18,310	12,361	31,552	2,430	2,386	4,816	36,368
1988	842	0	0	19,480	79,579	99,901	1,996	1,485	3,481	103,382
1989	1,059	0	0	13,395	26,218	40,672	1,000	1,409	2,409	43,081
1990	783	0	0	0	0	783	0	2,288	2,288	3,071
1991	1,009	0	0	0	21,826	22,835	0	2,050	2,050	24,885
1992	928	0	0	0	17,633	18,561	1,226	955	2,181	20,742
1993	2,364	0	0	7,803	137,888	148,055	7,093	6,088	13,181	161,236
1994	882	0	0	0	27,777	28,659	1,392	1,347	2,739	31,398
1995	1,603	16,124	0	0	103,836	121,563	16,053	4,819	20,872	142,435
1996	1,684	8,457	0	0	115,078	125,219	31,083	6,100	37,183	162,402
1997	1,547	16,999	0	0	84,336	102,882	20,733	4,008	24,741	127,623
1998	1,155	7,067	0	0	72,437	80,659	18,062	2,883	20,945	101,604
1999	1,350	399	0	3,767	110,410	115,926	15,963	2,112	18,075	134,001
Maximum	**2,364**	**16,999**	**8,001**	**19,480**	**241,801**	**246,913**	**42,685**	**6,439**	**49,124**	**255,593**
Minimum	**783**	**0**	**0**	**0**	**0**	**783**	**0**	**955**	**1,463**	**3,071**
Average	**1,322**	**3,184**	**545**	**4,013**	**79,962**	**89,026**	**10,280**	**3,337**	**13,618**	**102,643**

[1] For portion of EID located within KDWCD

Note: Exeter Irrigation District and Corcoran Irrigation Company water use calculated based upon acreage within KDWCD

4.12 CONVEYANCE LOSS CALCULATIONS

4.12.1 Background

The method used to estimate the delivery of surface water into each of the hydrologic units of the District is based upon the Kaweah River Entitlement Schedules that were established with the Kaweah and St. Johns Rivers Association Agreement (1974). The schedules were developed to allocate appropriated Kaweah River water to entitlement holders for the purposes of storage of such waters in Lake Kaweah and delivery from the lake to their diversion points (headgates) on the river. The schedules were set up based primarily on historical records of diversions and implementation of legal decisions prior to the 1962 completion of Terminus Dam.

The schedules are comprised of two basic components: the appropriator's headgate entitlement, and the conveyance water losses from Terminus Reservoir to the headgate. Conveyance, or seepage water loss, is defined as natural channel percolation, plus any riparian usage between headgate delivery points along the river. The data are summarized in Appendix B of the Task 4 Interim Report. The schedules are broken down first by the respective river, either the St. Johns River or Lower Kaweah River, then subdivided by month of the year with all entitlements and conveyance losses correlated to the range of natural Kaweah River flow at Terminus Dam. The conveyance losses for each respective river have been allocated to a specific length of that river, referred to as a reach loss.

Critical to the estimation of conveyance losses of delivered water is the available record data. The data utilized for estimating reach losses are listed as follows:

- Individual monthly diversions in af (1962 to 2000).
- Individual daily diversions in cubic feet per second (1990 to 2000).
- Individual daily storage and release data in cubic feet per second (1993-2000).

One of the primary reasons that the noted data periods were used was because they were readily available in electronic spreadsheet formats. Application of the data is detailed in the following section, which gives a description of the methodology used in estimating natural channel reach losses.

The basic methodology applied in estimating reach losses for the Lower Kaweah and St. Johns Rivers was use of the reach losses as identified on the entitlement schedule for each day that a reach had flow occurring. Water loss was allocated to that reach for each such day and the data were then summed into a monthly quantity for each year of the base period. Flow data in electronic spreadsheet format for daily diversion records were not available for the entire base period, although monthly diversion data were readily accessible. The determination was made to use the noted daily flow data to establish an average daily flow for each month of the year. This average flow was then divided into a correlating monthly diversion to estimate the number of days that any one diverter received entitlement water at their headgate during the base period. Once data had been complied, an estimate of days of flow occurring in a reach for any given month and year was made based on the headgate's downstream position relative to the upstream reach losses.

4.12.2 Natural Channels

The natural channels conveyance loss per month was estimated by multiplying the number of days that water flowed in the reach by the difference between an adjusted reach loss and any known riparian diversion with the reach. The adjusted reach loss was established by multiplying the schedule reach loss by the percentage of actual versus entitlement schedule cumulative losses for the St. Johns and Lower Kaweah Rivers individually. Actual cumulative losses for each river were established from daily storage and release records available electronically from 1993 to 2000.

The fundamental equation used in the calculation is as follows:

$$CL_M = D_F \bullet \left[\left(RL_S \bullet \left(\frac{RL_{ACT}}{RL_E} \right) \right) - R_d \right]$$

Where: CL_M = Conveyance loss in a month (af)
D_F = Number of days in a month when water flowed (days)
RL_S = Scheduled reach loss (af)
RL_{ACT} = Actual reach loss (af)
RL_E = Entitlement schedule cumulative reach loss (af)
R_d = Riparian Diversion (af)

As indicated in Table 22 - Summary of Conveyance Losses, Lower Kaweah and St. Johns River Systems, annual conveyance losses associated with the Lower Kaweah and St. Johns River Systems ranged from about 31,200 (1990) to 164,800 (1983) and averaged about 79,500 afy over the base period. These systems do not traverse Hydrologic Unit No. V. Most of the conveyance losses from these systems occurred within Hydrologic Unit No. II. Notable losses occurred during the years 1983, 1986, and 1998.

Table 22. Summary of Conveyance Losses, Lower Kaweah and St. Johns River Systems
(in acre-feet)

Calendar Year	Hydrologic Unit No. 1	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	12,052	22,300	4,173	7,505	0	9,491	**55,521**
1982	23,510	74,606	11,050	15,409	0	28,213	**152,788**
1983	24,049	81,834	9,383	13,197	0	36,376	**164,839**
1984	14,331	41,918	6,273	8,996	0	24,156	**95,674**
1985	13,823	29,324	5,850	8,631	0	9,283	**66,911**
1986	22,572	64,415	7,909	11,643	0	15,238	**121,777**
1987	11,534	14,967	3,603	5,642	0	5,061	**40,807**
1988	7,944	13,655	3,663	5,448	0	2,926	**33,636**
1989	8,066	15,885	3,531	5,579	0	3,090	**36,151**
1990	9,079	9,361	3,385	5,196	0	4,214	**31,235**
1991	13,430	22,562	4,074	6,596	0	3,838	**50,500**
1992	12,616	12,188	4,197	6,440	0	2,684	**38,125**
1993	19,339	39,010	8,890	13,301	0	14,596	**95,136**
1994	15,592	17,862	6,520	8,956	0	3,335	**52,265**
1995	23,648	62,949	8,876	12,419	0	22,432	**130,324**
1996	14,023	33,256	7,921	11,654	0	16,100	**82,954**
1997	19,079	46,371	7,055	11,112	0	14,524	**98,141**
1998	18,783	61,972	6,335	9,187	0	20,394	**116,671**
1999	9,588	20,390	3,870	5,516	0	7,958	**47,322**
Maximum	**24,049**	**81,834**	**11,050**	**15,409**	**0**	**36,376**	**164,839**
Minimum	**7,944**	**9,361**	**3,385**	**5,196**	**0**	**2,684**	**31,235**
Average	**15,424**	**36,043**	**6,135**	**9,075**	**0**	**12,837**	**79,515**
Lower Kaweah River Loss Reach	No. 2 (59%)		No. 4 (39%) No. 5 (100%) No. 6 (100%)	No. 2 (41%) No. 3 (100%) No. 4 (61%)			
St. Johns River Loss Reach	No. 1 (100%) No. 2 (89%)	No. 2 (11%) No. 3 (100%) No. 4 (100%) No. 5 (100%) No. 6 (100%) No. 7 (54%)				No. 7 (46%) No. 8 (100%) Highline Canal Losses	

4.12.3 Riparian Diversions

Quantification of surface water diverted on a monthly basis by riparian users for agricultural use was accomplished in concert with the calculation of reach losses along the Kaweah River system. Since the construction of Terminus Dam, the Kaweah and St. Johns Rivers Association has monitored the usage of surface water by landowners (riparian) adjacent to the rivers. Over the years, the Association has gone out daily during times when the river is flowing and collected riparian usage information, consisting mostly of pumping, in an effort to facilitate the delivery of entitlement water requested by downstream Association members.

The riparian usage data collected over the past several years is the most complete and accurate available, and was used to quantify average riparian daily diversions in each reach of the Lower Kaweah and St. Johns rivers. Again, the number of days in a given month that any one reach received surface water was multiplied by the average daily riparian diversions in that reach to compute riparian diversions for that month per each river reach. The monthly data were then compiled into yearly summaries for the study period and segregated by river reach consistent with the Association's entitlement schedules. These data are summarized in Table 23 - Summary of Riparian Diversions, Lower Kaweah and St. Johns River Systems. As indicated, over the base period "average" diversions for riparian use were on the order of 5,400 afy. Most riparian diversions occurred in Hydrologic Unit No. 2.

4.12.4 Headgate Diversion and Spills

Data used to account for the delivery of water into an entitlement holder's system was complied from Kaweah and St. Johns Rivers Association (Association) records. One of the primary purposes of the Association is to control the diversion and obtain measurements of daily flows into all the members' conveyance systems. Water is typically diverted from the river channel through a headgate control structure with a measuring station. The station normally consists of a stilling well with a Stevens 7-day water level chart recorder that is interconnected to a measuring flume. Charts are collected on a regular basis and the readings converted into average daily flow in cubic feet per second in accordance with the U.S. Department of the Interior, Bureau of Reclamation, "Water Measurement Manual." All such daily flow data are entered into a yearly record from October 1 to September 30, recognized as the “water year.”

Diversion records for all Association members are officially recorded and published in the "Annual Report to the Kaweah and St. Johns Rivers Association of the Discharge of the Kaweah River, Canal Diversions and Storage Operations." Such diversion records for Association members are also kept in a historical fashion relative to each diversion point. Data from the annual reports are summarized by diversion, per month, in af. The data are then organized and totaled for each water year. Historical diversion records are available from the water year starting in 1962, coinciding with the beginning of operations at Lake Kaweah, to the present.

Table 23. Summary of Riparian Diversions, Lower Kaweah and St. Johns River Systems
(in acre-feet)

Calendar Year	Hydrologic Unit No. 1	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	435	1,763	282	302	0	192	**2,974**
1982	744	8,430	633	517	0	1,834	**12,158**
1983	751	8,570	642	522	0	1,953	**12,438**
1984	435	3,847	357	302	0	972	**5,913**
1985	474	2,898	399	329	0	406	**4,506**
1986	737	5,769	561	512	0	1,155	**8,734**
1987	285	624	240	198	0	100	**1,447**
1988	274	623	225	190	0	82	**1,394**
1989	302	1,706	255	210	0	178	**2,651**
1990	218	298	177	151	0	0	**844**
1991	281	1,955	234	195	0	397	**3,062**
1992	190	583	162	132	0	91	**1,158**
1993	625	4,554	525	434	0	949	**7,087**
1994	228	1,049	195	158	0	82	**1,712**
1995	723	6,033	618	502	0	1,219	**9,095**
1996	550	4,985	465	383	0	1,077	**7,460**
1997	590	3,864	360	410	0	858	**6,082**
1998	751	7,077	642	522	0	1,542	**10,534**
1999	355	2,055	294	246	0	425	**3,375**
Maximum	**751**	**8,570**	**642**	**522**	**0**	**1,953**	**12,438**
Minimum	**190**	**298**	**162**	**132**	**0**	**0**	**844**
Average	**471**	**3,510**	**382**	**327**	**0**	**711**	**5,401**

All of the inflow/outflow delivery records were reviewed and compiled into a series of spreadsheets that are included in Appendix A of the Task 4 Interim Report. For any given system (river, canal, etc.), delivery data are provided in monthly increments for each (water) year of the base period. The delivery data were correlated to specific locations of diversion points within each of the six hydrologic units and then tabulated. The resultant delivery volumes are provided on Table 24 - Summary of Headgate Diversions.

Table 24. Summary of Headgate Diversions
(in acre-feet)

Calendar Year	Hydrologic Unit No. 1	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	9,495	26,955	21,941	75,859	85,116	110,383	**329,749**
1982	11,965	90,183	61,572	290,382	362,494	327,414	**1,144,010**
1983	8,193	85,869	63,357	306,831	366,024	275,829	**1,106,103**
1984	9,223	51,055	36,481	140,442	191,931	218,358	**647,490**
1985	8,553	43,449	24,345	107,743	114,275	121,721	**420,086**
1986	7,500	66,212	45,911	205,190	315,048	169,322	**809,183**
1987	7,825	19,746	16,735	54,323	17,910	70,360	**186,899**
1988	6,931	21,520	18,399	61,627	90,941	51,030	**250,448**
1989	8,068	28,641	16,501	64,493	50,099	46,853	**214,655**
1990	8,302	14,207	13,373	34,168	586	42,141	**112,777**
1991	7,895	29,583	14,833	77,424	68,017	50,697	**248,449**
1992	6,967	16,236	9,987	43,694	29,473	27,456	**133,813**
1993	9,453	60,773	29,439	176,566	253,172	197,047	**726,450**
1994	7,646	23,647	13,394	53,011	49,632	35,821	**183,151**
1995	16,265	89,215	43,576	247,369	271,461	288,781	**956,667**
1996	11,074	56,081	27,865	181,336	250,303	240,196	**766,855**
1997	11,044	56,136	29,207	212,705	223,103	179,640	**711,835**
1998	13,470	92,094	50,671	243,077	295,307	221,512	**916,131**
1999	9,531	32,749	21,204	95,444	130,441	99,870	**389,239**
Maximum	**16,265**	**92,094**	**63,357**	**306,831**	**366,024**	**327,414**	**1,144,010**
Minimum	**6,931**	**14,207**	**9,987**	**34,168**	**586**	**27,456**	**112,777**
Average	**9,442**	**47,597**	**29,410**	**140,615**	**166,596**	**146,023**	**539,684**
Diversions	Hamilton Hanna Longs Ketchum PackwoodCana l Fisher Exeter ID (3.7%)	Mathews Uphill Modoc St. Johns Goshen Harrell Ranch	TIC (5%) Fleming Oaks Packwood Creek (10%) Evans Persian Watson	Yokohl Creek Peoples Deep Creek Exeter ID (5.3%) TID (10%) TID: Wutchumna (10%) TID: CVP (10%) Crocker Cut (10%) TIC (5%)	Crocker Cut (90%) TIC (90%) Packwood Creek (90%) TID (90%) TID: Wutchumna (90%) TID: CVP (90%)	Cross Creek Spill (110%) Lakeside (Total) CIC (5.43%) CIC: Kings (5.43%)	

Notes:
1 CVP water is included in all headgate diversions with the exception of the CVP water that flows through the Friant-TID Parshall and noted as TID:CVP
2 Lakeside (Total) includes Kaweah, Kings and CVP water.

As indicated in Table 24, there was an average of about 539,700 afy of surface water directed at headgates within the District over the base period. This volume includes both local and imported water sources. Most of the CVP deliveries were to Hydrologic Unit No. V, which receives virtually all of the CVP water (80,000 afy of 89,000 afy total over the base period).

4.12.5 Constructed Channels

Seepage losses that occur in constructed channels were estimated in the following manner. A percentage of the water delivered to the appropriator's headgate was estimated for channel losses in the conveyance system. This percentage was then multiplied by the monthly diversion to each system for each year of the base period. The loss percentage was estimated in two different ways. The preferred method was to take the last 5 years of headgate diversion records and compare that to the ditch company's annual report for water deliveries to stockholders. The difference between the yearly headgate diversion amount and stockholder deliveries was the amount used in estimating the loss percentage. The equation used to calculate the loss percentage is provided as follows.

$$\text{Loss Percentage} = \frac{(D_{HG} - D_{SH} - D_{RB})}{(D_{HG} - D_{RB})}$$

where: D_{HG} = Volume of water delivered to headgate for diversion (af),
D_{SH} = Volume of water delivered to stock holders (af), and
D_{RB} = Volume of water delivered to recharge basins (af).

The exception to the preferred method was for those few ditch companies that did not have or would not make available annual reports of water deliveries to stockholders. These companies were interviewed and their percentages were based on estimates by the operations supervisor for the company.

The loss factor was multiplied by the total volume of water diverted to a service area to derive the total quantity of water that percolated through unlined channels. These loss factors, expressed as percentages, are summarized on Table 25 - Ditch System Conveyance Loss Percentages. Most service areas indicated in Table 25 are served by a single diversion point from either the St. Johns or Lower Kaweah Rivers. TID and Tulare Irrigation Company receive water from six independent diversions: St. Johns River, Wutchumna Water Company, Packwood Creek, TIC, Friant-Kern Canal (CVP water), and Crocker Cut.

Other sources of surface water supply and associated losses not directly associated with the Kaweah River system include Yokohl Creek, Lewis Creek, and Cottonwood Creek. Because Yokohl Creek flows directly into the Consolidated Peoples system, the loss factor for that system was also applied to Yokohl Creek. Flow from Lewis Creek is sufficiently low to be ignored for purposes of this study.

Cottonwood Creek joins St. Johns River at the northwest corner of Hydrologic Unit No. II. The flow gauge on Cottonwood Creek was located significantly outside of the District before 1992, at which time the gauge was moved to a location within the District boundary. Before 1992, the quantity of water that reached the District was unknown.

Table 25. Ditch System Conveyance Loss Percentages

Service Area	Hydrologic Unit No.	Loss Percentage	Diversion Source
Hamilton Ditch Company	I	0%	Lower Kaweah
Longs Canal	I	0%	Saint Johns River
Wutchumna Water Company	I	5%	Kaweah River
Goshen Ditch Company	II	25%	St. Johns River
Mathews Ditch Company	II	11%	St. Johns River
Modoc Ditch Company	II	15%	St. Johns River
St. Johns Ditch Company	II	25%	St. Johns River
Uphill Ditch Company	II	22%	St. Johns River
Flemings Ditch Company	III	26%	Lower Kaweah
Oakes Ditch Company	III	29%	Lower Kaweah
Evans Ditch Company	III	28%	Mill Creek
Persian/Watson Ditch Companies	III	28%	Mill Creek
Consolidated Peoples and Elk Bayou Ditch Companies	IV	31%	Lower Kaweah
Farmers Ditch Company	IV	41%	Lower Kaweah
Yokohl Creek	IV	31%	Yokohl Creek
Tulare Irrigation District and Tulare Irrigation Company	V	34%	St. Johns, Wutchumna, Friant, Lower Kaweah, TIC Canal
Lakeside Ditch Company	VI	15%	Cross Creek and Lakeland Canal

Surface water flow in Cottonwood Creek is ephemeral and occurs temporarily at high volumes. Further, it is assumed little water from Cottonwood Creek is diverted to riparian users as flow occurs mainly during wet periods.

Based on the developed loss percentages, a summary of the estimated annual quantities of conveyance losses within each hydrologic unit related to the channel systems is tabulated in Table 26 - Summary of Ditch Systems Conveyance Losses. Average losses in the constructed channels (ditches) were on the order of 128,700 afy over the base period. These data are, in turn, combined with the conveyance losses related to the Lower Kaweah and St. Johns River systems (Table 22) as Table 27 - Summary of All Delivered Water Conveyance Losses. As indicated, average annual losses within the District are estimated at about 208,100 afy and ranged from a high of about 433,000 af in 1983 to a low of about 49,000 af in 1990. Plates 52 through 58 - Percolation of Surface Water, graphically present the components of percolation for the natural channels (Lower Kaweah and St. Johns Rivers), the constructed channels, and artificial release basins for the entire District and each of the six hydrologic units for each year of the base period.

Table 26. Summary of Ditch System Conveyance Losses
(in acre-feet)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	0	4,250	6,444	30,955	22,697	6,599	**70,945**
1982	261	12,714	21,376	117,999	96,665	25,518	**274,533**
1983	0	13,358	23,490	109,065	97,606	24,664	**268,183**
1984	0	7,662	12,318	58,282	51,182	17,225	**146,669**
1985	40	5,972	7,435	44,114	30,473	8,862	**96,896**
1986	0	9,793	18,409	85,767	84,012	16,156	**214,137**
1987	17	2,947	4,762	18,866	4,775	4,914	**36,281**
1988	9	3,336	5,187	26,364	24,251	4,372	**63,519**
1989	32	4,395	4,887	24,618	13,360	3,913	**51,205**
1990	10	2,078	3,720	10,485	157	1,264	**17,714**
1991	35	4,216	4,432	30,648	18,138	3,938	**61,407**
1992	16	2,409	2,788	15,916	7,859	1,144	**30,132**
1993	69	7,870	9,315	78,603	67,513	15,710	**179,080**
1994	16	3,355	3,785	20,851	13,235	1,772	**43,014**
1995	208	11,716	14,667	100,146	72,389	22,910	**222,036**
1996	165	8,060	9,925	77,017	66,748	18,050	**179,965**
1997	67	7,510	9,926	83,340	59,494	15,169	**175,506**
1998	458	12,140	17,384	92,143	78,749	20,521	**221,395**
1999	37	4,789	7,187	38,284	34,784	6,912	**91,993**
Maximum	**458**	**13,358**	**23,490**	**117,999**	**97,606**	**25,518**	**274,533**
Minimum	**0**	**2,078**	**2,788**	**10,485**	**157**	**1,144**	**17,714**
Average	**76**	**6,767**	**9,865**	**55,972**	**44,426**	**11,559**	**128,664**
Systems with Losses	Ketchum (10%) Packwood Canal (10%)	Mathews (11%) Uphill (22%) Modoc (15%) St. Johns (25%) Goshen (25%)	TIC (5%) Fleming (26%) Oakes (29%) Packwood Creek (10%) Evans (28%) Persian (28%) Watson (28%)	Peoples (31%) Deep Creek (41%) TID (10%) Crocker Cut (10%) TIC (5%)	Crocker Cut (24%) TIC (24%) Packwood Creek (24%) TID (24%)	Lakeside (15%) CIC (3%) CIC: Kings (10%)	
Systems without Losses	Hamilton Hanna Longs Fisher Exeter ID	Harrell Ranch		Exeter ID			

Table 27. Summary of All Delivered Water Conveyance Losses
(in acre-feet)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	12,052	26,550	10,617	38,460	22,697	16,090	**126,466**
1982	23,771	87,320	32,426	133,408	96,665	53,731	**427,321**
1983	24,049	95,192	32,873	122,262	97,606	61,040	**433,022**
1984	14,331	49,580	18,591	67,278	51,182	41,381	**242,343**
1985	13,863	35,296	13,285	52,745	30,473	18,145	**163,807**
1986	22,572	74,208	26,318	97,410	84,012	31,394	**335,914**
1987	11,551	17,914	8,365	24,508	4,775	9,975	**77,088**
1988	7,953	16,991	8,850	31,812	24,251	7,298	**97,155**
1989	8,098	20,280	8,418	30,197	13,360	7,003	**87,356**
1990	9,089	11,439	7,105	15,681	157	5,478	**48,949**
1991	13,465	26,778	8,506	37,244	18,138	7,776	**111,907**
1992	12,632	14,597	6,985	22,356	7,859	3,828	**68,257**
1993	19,408	46,880	18,205	91,904	67,513	30,306	**274,216**
1994	15,608	21,217	10,305	29,807	13,235	5,107	**95,279**
1995	23,856	74,665	23,543	112,565	72,389	45,342	**352,360**
1996	14,188	41,316	17,846	88,671	66,748	34,150	**262,919**
1997	19,146	53,881	16,981	94,452	59,494	29,693	**273,647**
1998	19,241	74,112	23,719	101,330	78,749	40,915	**338,066**
1999	9,625	25,179	11,057	43,800	34,784	14,870	**139,315**
Maximum	**24,049**	**95,192**	**32,873**	**133,408**	**97,606**	**61,040**	**433,022**
Minimum	**7,953**	**11,439**	**6,985**	**15,681**	**157**	**3,828**	**48,949**
Average	**15,500**	**42,810**	**16,000**	**65,047**	**44,426**	**24,396**	**208,178**

Note: Values represent natural river system and ditch system (constructed channel) conveyance losses.

4.13 ARTIFICIAL RECHARGE

4.13.1 General Characteristics

Since the 1930s, the District has operated groundwater recharge ("sinking") basins for purposes of conserving available water supply and flood control within the District. Information on the history of the development, operation, size, location, approximate diversions, maintenance, and other features of each recharge basin are available from the District in various forms. A summary of the characteristics of each recharge basin is provided in Table

28 - Recharge Basin Inventory. A map of the location of each recharge basin is provided on Plate 10, keyed to the information provided in Table 28.

As indicated, the District presently operates about 40 recharge basins with a combined surface area of about 2,100 acres. B&E (1972, pg. VI-16) provided a brief summary of District recharge activities as of about 1970. At that time, there were about 36 spreading basins both in and immediately adjacent the District, covering some 4,600 acres, with an estimated recharge capacity of 1,100 af per day. Total volumes of annual average recharge to the District were not directly provided by B&E.

Recharge basins in the District serve to supplement natural replacement to the groundwater reservoir and channel loss contributions. Although the source of supply for each recharge basin is variable from year to year, the approximate quantities of artificial recharge can be estimated for each year of the base period for each hydrologic unit. It should be noted that a recharge basin site is linked to the disposal of treated wastewater from the City of Visalia, which is from time to time in excess of the needs of disposal by irrigation. Tabulation and accounting of inflows depends on the accuracy of data relating to the number of days per year of wetted area in each basin and the hydraulic conductivity or percolation capacity of the basin, typically expressed in units of gallons per day per square foot or in af per day per acre.

4.13.2 Record Data

Prior to the completion of Terminus Dam, the District compiled available data into a basin list including percolation rates. The data were integrated into the United States Army Corps of Engineers' "Reservoir Regulation Manual" for Terminus Dam. Prior to the dam's construction, the District used the basins during periods of excess water flows in the Kaweah River system to help minimize the effects of potential flooding to downstream parties, while simultaneously taking advantage of the opportunity to recharge groundwater.

Table 28. Recharge Basin Inventory

No.	Name	Hydraulic Unit No.	Location (Township-Range-Section)	Supply	Date of Purchase	Acreage	Capacity (af)	Approximate Rate of Percolation (af per day)
99	Peoples	I	18-26-14	Lower Kaweah River	1999	N/A	N/A	N/A
105	Hannah Ranch	I	18-27-07	Lower Kaweah River	2001	N/A	N/A	N/A
107	Curtis	I	18-27-06	St. Johns River	2001	N/A	N/A	N/A
5	Willow School	II	18-24-14	Modoc Ditch	1958	50	200	25
22	Shannon-Modoc (CPC)	II	18-24-13	Modoc Ditch	Lease: 1959	10	50	4
28	Doe-Goshen	II	18-24-09	Goshen Ditch	Lease: 1962	20	80	10
30	Harrell	II	17-24-34	Harrell No. 1	Lease: 1963	50	200	40
9	Goshen	II	18-24-18	Modoc Ditch	Lease: 1955	40	160	10
26	Doe-Ritchie	II	18-24-21	Modoc Ditch	Lease: 1961	20	80	10
43	Oakes	III	19-25-25	Lower Kaweah River	1997	23	36	23
4	Packwood	III	18-23-03	South Mill Creek	1940	160	800	35
12	Goshen Pit	III	18-24-30	North Mill Creek	1957	12	185	5
13	Nelson Pit	III	19-24-09	Evans Ditch	1950	34	340	14
31	Hammer	IV	19-25-02	Consolidated Peoples Ditch	Lease: 1965	3	6	1
32	Bill Clark	IV	19-25-11	Consolidated Peoples Ditch	Lease	2	5	1
44	Hutcheson West	IV	18-25-36	TID Canal	1999	N/A	N/A	N/A
45	Hutcheson East	IV	18-25-36	Cameron Creek	1999	N/A	N/A	N/A
108	Paregien	IV	18-26-32	Deep Creek	2001	N/A	N/A	N/A
1	Art Shannon	IV	19-25-23	Farmers Ditch	1969	22	180	20
7	Gary Shannon	IV	19-25-32	Farmers Ditch	1969	5	30	4
21	Gordon Shannon	IV	19-25-34	Farmers Ditch	1962	47	95	6
24	Anderson	IV	20-25-17	Farmers Ditch	1960	147	600	20
27	Ellis	IV	20-25-16	Farmers Ditch	Lease: 1962	3	30	4
29	Nunes	IV	20-25-03	Farmers Ditch	1963	40	250	30

Table 28. (Continued)

No.	Name	Hydraulic Unit No.	Location (Township-Range-Section)	Supply	Date of Purchase	Acreage	Capacity (af)	Approximate Rate of Percolation (af per day)
95	Sunset	IV	20-25-01	Inside Creek	1973	103	320	60
106	Elk Bayou	IV	20-24-36	Elk Bayou Creek	Lease: 2001	6	22	3
16	Creamline	V	19-25-20	TID Canal	1972	153	535	85
3	Colpien	V	19-23-22	Tulare Canal	1940	160	640	60
6	Machado	V	19-23-35	Packwood Creek	1942	166	665	80
11	Tagus	V	19-24-15	Packwood Creek	1949	80	800	150
14	Abercrombie	V	20-24-23	Tulare Canal	1953	20	80	5
2	Enterprise	V	19-24-29	Tulare Canal	1940	20	100	8
8	Corcoran Hwy.	V	20-23-10	Packwood Creek	1945	120	480	40
17	Franks	V	20-23-06	Tulare Canal	1957	40	160	6
18	Guinn	V	20-23-30	Tulare Canal	1957	168	675	25
19	Franks	V	20-23-06	Tulare Canal	1958	130	520	16
20	Wilbur	V	20-23-34	Tulare Canal	1959	20	90	10
25	Doris	V	21-23-06	Cameron Creek	1962	15	60	7
10	Lakeside	VI	19-22-10	Lakeside Ditch	1946	187	800	150
15	Howe	VI	20-22-07	Lakeside Ditch	1954	53	210	15
23	Green	VI	19-22-21	Lakeside Ditch	1960	4	15	1
					Total Basin Area:	**2,133**	**9,499**	**983**
Other Basins								
1	Lakeside	VI	18-22-35	Lakeside Ditch		320	1,100	60
1-3	Corcoran 1,2,3	VI	20-22-21,28,35	Cross Creek		2,400	9,000	200

Note: N/A represents basin sites that are not currently developed.

During the District's history, available inflow records to the recharge basins have been limited and further research has revealed that such records do not adequately exist for the base period. The approach for estimating inflow from a recharge basin was therefore based on approximating the number of days any one basin might have received water. The data utilized for estimating recharge basin inflow are listed as follows:

- Individual monthly diversions in af (1962 to 2000).
- Individual daily diversions in cubic feet per second (1990 to 2000).
- Anticipated irrigation demand derived from the calculation of gross required irrigation demand (Task 6) - Interim Report.
- Recharge basin percolation rates from the U.S.A.C.E., Terminus Dam, "Reservoir Regulation Manual."

The application of the noted data is detailed in the following section, which gives a description of the methodology used in estimating inflow from the recharge basins within the District.

4.13.3 Calculations

The basic methodology applied in estimating recharge basin inflow was to multiply the number of days a basin received water by the basin's percolation rate. The approximation of days that a basin received water was conditional on such recharge water being delivered only after anticipated irrigation demand was met. The critical element in the process was developing a recharge factor based on river system flow conditions. The factor was used to adjust the number of days a basin received water in correlation to the water conditions present in the system for any given month. The factor was an adjustment based on the probability that a basin received more water during higher water flows months versus lower flow months. The first step in calculating a factor was to compile monthly flows into the Kaweah River system from 1970 to 2000 and then normalize the data. For those months when flow into the Kaweah River system was greater than the anticipated irrigation demand, a factor was established by prorating the normal distribution of that month's flow with the normal distribution of the amount for average monthly anticipated irrigation demand. The average monthly anticipated irrigation demand for the study period was determined by using the difference between full crop water usage (evapotranspiration) and effective precipitation during a given month for the crop usage within the District's boundaries.

Once the recharge factor was calculated, the number of days a basin received water was determined by multiplying the number of days in a given month that its delivery system received water through the headgate (as previously estimated in the reach loss calculations), times the recharge factor. This estimation of days was then used with the basin's percolation rate to determine inflow (recharge) for that month. For times when the monthly flow into the Kaweah River system did not meet average monthly anticipated irrigation demand, the recharge factor was zero, thereby resulting in no days of recharge for basins within the District. Recharge basin summary dates are contained in Appendix C of the Task 4 Interim Report.

The results of the analyses are tabulated below in Table 29 - Summary of Recharge Basin Inflow.

Table 29. Summary of Recharge Basin Inflow

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	0	187	17	433	3,423	483	**4,543**
1982	0	16,232	4,177	24,057	81,197	57,359	**183,022**
1983	0	26,874	7,577	38,445	141,304	90,697	**304,897**
1984	0	4,646	2,059	7,577	29,428	16,585	**60,295**
1985	0	1,420	542	4,243	12,794	3,389	**22,388**
1986	0	9,466	4,031	14,870	47,357	23,699	**99,423**
1987	0	84	49	501	1,778	361	**2,773**
1988	0	117	62	1,039	2,143	380	**3,741**
1989	0	37	6	58	184	77	**362**
1990	0	0	0	45	24	0	**69**
1991	0	78	37	258	254	200	**827**
1992	0	98	70	633	207	108	**1,116**
1993	0	4,277	1,456	7,130	24,550	11,290	**48,703**
1994	0	73	27	750	0	79	**929**
1995	0	12,503	5,363	18,224	61,396	42,873	**140,359**
1996	0	7,413	3,146	12,919	41,197	21,442	**86,117**
1997	0	7,545	3,616	12,694	39,597	26,638	**90,090**
1998	0	15,787	6,814	24,794	84,828	58,597	**190,820**
1999	0	671	169	1,200	3,902	2,704	**8,646**
Maximum	**0**	**26,874**	**7,577**	**38,445**	**141,304**	**90,697**	**304,897**
Minimum	**0**	**0**	**0**	**45**	**0**	**0**	**69**
Average	**0**	**5,658**	**2,064**	**8,941**	**30,293**	**18,787**	**65,743**
Basins		5, 9, 22, 26, 28 and 30	4 and 13	1, 7, 21, 24, 27, 29, 31, 32, and 95	2, 3, 6, 8, 11, 14, 16, 17, 18, 19, 20, and 25	10, 15, 23, Lakeside 1 & 2, CID 1, 2 & 3	

Average annual inflow into the recharge basins is on the order of 65,700 afy and ranged from a high of about 304,900 af in 1983 to a low of 69 af in 1990. By comparison, B&E (1972) estimated a total infiltration capacity in the District of about 1,114 afy (condition prevalent in the late 1960s), but did not provide an actual estimate of annual artificial recharge volumes of their 5-year base period (1962 to 1966).

4.14 CROP DELIVERY

Delivery of surface water to meet agricultural crop demands in the District is derived from the headgate diversions (Table 24) less the ditch system conveyance losses (Table 26), less the return spills (discussed later in Table 32), less surface water artificially recharged (Table 29), plus the riparian diversions (Table 23).

The fundamental equation used in the calculation is as follows:

$$SW_C = HG_{DIV} - CL_{DITCH} - AR - S + R_D$$

where:
- SW_C = Surface Water Crop Delivery
- HG_{DIV} = Headgate Diversions
- CL_{DITCH} = Conveyance Loss Constructed Channel
- AR = Artificial Recharge
- S = Spills (surface water outflow)
- R_D = Riparian Diversion

Annual volumes of surface water delivered to farms are summarized in Table 30 - Summary of Surface Water Crop Delivery Data. As indicated, the average annual amount of surface water delivered to meet crop demand was about 251,300 afy over the base period. The deliveries show an obvious correlation to the availability of surface water and ranged from about 56,000 afy (1990) to 462,800 afy (1982).

Table 30. Summary of Surface Water Crop Delivery Data
(in acre-feet)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	9,930	24,281	15,762	44,773	58,254	25,008	**178,008**
1982	12,448	69,667	36,652	118,614	151,385	74,008	**462,774**
1983	8,944	54,207	32,932	63,221	29,936	48,009	**237,249**
1984	9,658	42,594	22,461	69,341	99,299	64,525	**307,878**
1985	8,987	38,955	16,767	59,715	70,641	35,828	**230,893**
1986	8,237	52,722	24,032	86,899	158,461	58,649	**389,000**
1987	8,093	17,339	12,164	35,154	11,357	20,740	**104,847**
1988	7,196	18,690	13,375	34,414	64,547	20,487	**158,709**
1989	8,338	25,915	11,863	40,027	36,555	18,491	**141,189**
1990	8,510	12,427	9,830	23,789	405	1,024	**55,985**
1991	8,141	27,244	10,598	46,713	49,625	18,059	**160,380**
1992	7,141	14,312	7,291	27,277	21,407	2,853	**80,281**
1993	10,009	53,180	19,193	91,267	161,109	62,535	**397,293**
1994	7,858	21,268	9,777	31,568	36,397	5,676	**112,544**
1995	16,780	71,029	24,164	118,001	135,399	74,001	**439,374**
1996	11,459	45,593	15,259	91,547	142,358	62,528	**368,744**
1997	11,567	44,945	16,025	91,488	109,483	51,308	**324,816**
1998	13,763	71,244	27,115	105,862	125,799	54,668	**398,451**
1999	9,849	29,344	14,142	54,401	91,325	27,324	**226,385**
Maximum	**16,780**	**71,244**	**36,652**	**118,614**	**161,109**	**74,008**	**462,774**
Minimum	**7,141**	**12,427**	**7,291**	**23,789**	**405**	**1,024**	**55,985**
Average	**9,837**	**38,682**	**17,863**	**64,951**	**81,776**	**38,196**	**251,305**
Inflow	Hamilton Hanna Longs Ketchum Packwood Canal Fisher Exeter ID (3.7%)	Mathews Uphill Modoc St. Johns Goshen Harrell Ranch	TIC (5%) Fleming Oakes Packwood Creek (10%) Evans Persian Watson	Yokohl Creek Peoples Deep Creek Exeter ID (5.3 %) TID (10%) TID: Wutchumna (10%) TID: CVP (10%) Crocker Cut (10%) TIC (5%)	Crocker Cut (90%) TIC (90%) Packwood Creek TID (90%) TID: Wutchumna (90%) TID: CVP (90%)	Cross Creek Spill (110%) Lakeside (Total) CIC (5.43%) CIC: Kings (5.43%)	
Outflow	Ditch System Losses	Ditch System Losses Recharge Basins	Ditch System Losses Recharge Basins	Ditch System Losses Recharge Basins Elk Bayou Spill	Ditch System Losses Recharge Basins TID Spill	Ditch System Losses Recharge Basins Cross Creek Spill	
Land Use: Irrigated Agriculture	12,000	38,000	20,000	45,000	67,000	70,000	252,000
Surface Water Delivery/ Irrigated Agriculture	0.89	1.12	0.88	1.45	1.31	0.46	1.02

Notes:
1) CVP water is included in all headgate diversion with the exception of the CVP water that flows thru the Friant- TID Parshall and noted as TID: CVP.
2) Lakeside (Total) includes Kaweah, Kings, and CVP water.

B&E (1972) approached the tabulation of the delivery of surface water to each of the six hydrologic units in a manner similar to this study. The period of their analysis was from 1961 to 1965. A summary of the net volume of inflow calculated by B&E (1972, Table V-8) is provided below in Table 31 - Summary of Surface Water Delivery Data, as a comparison to the results this study. It should be noted that the hydrologic unit boundaries differ (in some cases materially) in both studies and B&E combines both diversions (aka, deliveries) and channel losses.

Table 31. Comparative Summary of Surface Water Delivery Data
(in acre-feet)

		Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
Fugro	Diversions (Crop Delivery)	9,837	38,682	17,863	64,951	81,776	38,196	**251,305**
	Channel Losses	15,500	42,810	16,000	65,047	44,426	24,396	**208,179**
	Artificial Recharge	0	5,658	2,064	8,941	30,293	18,787	**65,743**
	Total Diversions & Channel Losses, Artificial Recharge	**25,337**	**87,150**	**35,927**	**138,939**	**156,495**	**81,379**	**525,227**
B&E, 1972	**Diversions and Channel Losses**	**44,000**	**83,500**	**56,000**	**105,700**	**162,800**	**106,900**	**558,900**

4.15 SURFACE WATER OUTFLOW (SPILLS)

In years of significant surface water availability within the District (i.e., 1983, 1995, 1997), the quantity of surface water can exceed the crop demands and recharge capacity of the conveyance systems and basins. In such years, surface water flows out of the District in the form of "spills." Three spill locations are recognized in the District at points on Elk Bayou to the Tule River, from TID to the Tule River, and from Cross Creek to (ultimately) the Tulare Lake bed. Quantification of these spills at these points (refer to Figure 2) is straightforward in that these spill points are gauged. Table 32 - Summary of Spills, tabulates the volumes of spill from the District at the designated points for each year of the base period. In many years, no spill occurs. As indicated, the average volume of spill was about 99,400 afy over the base period, most of which being concentrated in 1983, 1995, and 1997.

Table 32. Summary of Spills
(in acre-feet)

Calendar Year	Hydrologic Unit No. 1	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	0	0	0	0	742	78,485	**79,227**
1982	0	0	0	30,229	33,247	172,363	**235,839**
1983	0	0	0	96,622	97,178	114,412	**308,212**
1984	0	0	0	5,544	12,022	120,995	**138,561**
1985	0	0	0	0	367	74,048	**74,415**
1986	0	0	0	18,166	25,218	71,973	**115,357**
1987	0	0	0	0	0	44,445	**44,445**
1988	0	0	0	0	0	25,873	**25,873**
1989	0	0	0	0	0	24,550	**24,550**
1990	0	0	0	0	0	39,853	**39,853**
1991	0	0	0	0	0	28,897	**28,897**
1992	0	0	0	0	0	23,442	**23,442**
1993	0	0	0	0	0	108,461	**108,461**
1994	0	0	0	0	0	28,376	**28,376**
1995	0	0	0	11,500	2,277	150,216	**163,993**
1996	0	0	0	236	0	139,253	**139,489**
1997	0	0	0	25,593	14,529	87,383	**127,505**
1998	0	0	0	20,800	5,931	89,268	**115,999**
1999	0	0	0	1,805	430	63,355	**65,590**
Maximum	**0**	**0**	**0**	**96,622**	**97,178**	**172,363**	**308,212**
Minimum	**0**	**0**	**0**	**0**	**0**	**23,442**	**23,442**
Average	**0**	**0**	**0**	**11,079**	**10,102**	**78,192**	**99,373**
Outflow from Hydrologic Unit				Elk Bayou Spill to Tule River	TID Spill to Tule River	CIC to Tulare Lakebed	

CHAPTER 5 - WATER QUALITY

5.1 INTRODUCTION

Presented in this chapter is a discussion of the quality of groundwater and surface water in the District with emphasis on spatial and temporal quality variations. To accomplish this, readily available surface and groundwater water quality data were collected, compiled, and reviewed. However, significant data gaps in both the period of record and data consistency were found to be a significant limiting factor in this study. It should be noted that the District, per se, has not undertaken any water quality studies (other than what is contained in B&E [1972]) and is not a repository for ground and surface water quality data. As a result of these data gaps, the District requested that the review and discussion of water quality data be narrowed considerably as part of the WRI.

5.2 SOURCES OF SURFACE AND GROUNDWATER QUALITY DATA

5.2.1 State of California Department of Water Resources

During the Task 1 activities, the DWR was contacted and queried as to the extent of their groundwater quality database. The DWR provided tabulated data for approximately 100 water wells that had been sampled from one to 20 times over the base period. All but six of these wells were located outside the District boundaries. Data from four of the six wells located within the District were used to prepared Stiff Diagrams, discussed below. Copies of the available data obtained from the DWR were included in the Task 5 - Interim Report.

5.2.2 Regional Water Quality Control Board - Central Valley Region

The RWQCB (Fresno office) was contacted to obtain data pertaining to groundwater monitoring at several wastewater treatment facilities and waste discharge issues at numerous dairy farms within the District.

Further inquiry conducted for the subject study revealed that limited published data were available pertaining to the numerous dairy farms within the District. This is primarily because waste discharges and related groundwater monitoring activities from dairies have only recently fallen under RWQCB oversight. As such, the data they currently maintain are recent (i.e. generally less than 2 years old) and has not been assembled in to any readily accessible or useful database. Procurement of the limited data available was outside the scope of the water quality evaluation.

Groundwater quality data related to groundwater monitoring activities conducted at wastewater treatment facilities within the District was also investigated. The nature of the data was viewed to be of marginal value to the study and in addition, was not in a readily available format. As such, these data were not utilized for the study.

5.2.3 United States Environmental Protection Agency

Review of the Legacy Data Center (LDC) system identified approximately 1,634 water quality data sets from groundwater wells located in the vicinity of the District; limited data were also identified in the Modernized STORET (i.e. the EPA's database for recent [<3 yrs old] data). A data set represents one sample collection date at a particular well location; therefore, one well may have multiple data sets.

These data were downloaded from the EPA. It was determined that the majority of the groundwater quality data points were outside of the District boundaries; however, surface water quality data collected from eleven locations within the District was obtained from the EPA database and were useful. The groundwater quality data were insufficient in both period of record and consistency for use in the study; the surface water quality data are discussed below. Copies of the EPA data obtained were included in the Task 5 Interim Report.

5.2.4 California Water Services Company

Cal Water provided analytical data for the approximately 80 active, standby, or abandoned water wells that service the Visalia area, and for three active wells that service an area south of Visalia, known as Tulco. These active water wells, and other wells in and adjacent the District that fall under California State Department of Health Services permitted systems, are routinely monitored for depth to water and general mineral constituents in accordance with the California Code of Regulations, Title 22.

Title 22 requires testing each well at the time of construction, annual testing of each well in the system for nitrate (and other selected constituents), and monthly testing of each well in the system for bacteriological organisms. However, it was discovered that these data were more sporadic in terms of frequency and constituents of analysis than the testing requirements suggest. In addition, the Cal Water wells are heavily concentrated in the immediate vicinity of the City of Visalia. Selected data obtained from Cal Water was included in the preparation of Stiff Diagrams (i.e. the data were also provided by the DWR), discussed below.

5.2.5 Kings County Health Department

The KHD was contacted as to any groundwater monitoring programs they administer in or adjacent to the District. The only information relevant to the subject study provided by the KHD consisted of Consumer Confidence Reports for four facilities: three with one water supply well, and one with two water supply wells. All four of these facilities (the Kings Waste & Recycling Authority, Kit Carson School, Hamblin Mutual Water Company, and Gilroy Foods) are located just west of the northwestern boundary of the District. Additionally, these data were insufficient in both periods of record and consistency for use in the study.

5.2.6 City of Visalia Public Works Department

During the Task 1 activities, the VPWD was contacted about any groundwater monitoring programs they administer within the study area. At that time, the VPWD made available two documents of limited value and applicability to the subject study. The first document, titled *Groundwater Investigation Report, Visalia Water Conservation Plant,* dated January 30, 1998, describes the activities and findings of a groundwater investigation related to contamination by dissolved salts in groundwater believed to be related to wastewater discharge beneath the Visalia Water Conservation Plant located in Visalia, within the District. These data were restricted to the immediate vicinity of the Water Conservation Plant, and was insufficient in both period of record and consistency for use in the study.

The second document provided by the VPWD is titled *Groundwater Monitoring Program, Spring 2001 Semi-Annual Data Transmittal,* dated June 22, 2001, documents groundwater monitoring activities conducted at the Visalia Water Conservation Plant under Waste Discharge Requirements (Order No. 97-061) issued by the RWQCB. Because the data provided by this document originates from monitoring wells positioned within locally impacted groundwater, these data were not viewed as representative of this area of the District and as such was not appropriate for the study.

5.2.7 Tulare County Resources Management Agency - Solid Waste Division

Within the District, the City of Tulare operates the Tulare Waste Water Treatment Facility, which is located approximately 1-1/2 miles west of the City of Tulare. For the subject study, the TRMA provided a *Draft Facilities Plan* and two other documents that were prepared by a consultant to the City of Tulare that describe point source assessment activities and a groundwater monitoring program developed to monitor discharges from the Treatment Facility (under RWQCB issued Waste Discharge Requirements). However, it was determined that the Lead Enforcement Agency, the RWQCB, has recently taken issue with existing monitoring wells that have been designated background water quality monitoring points at the Treatment Facility. Specifically, the RWQCB does not believe samples from these wells represent native groundwater quality in the vicinity of the Treatment Facility. As point source data are not representative of actual groundwater conditions, rather they are focused on a local area of contamination; these data were not appropriate for the subject study.

5.3 GENERAL DISCUSSION OF WATER QUALITY ISSUES

5.3.1 General Minerals

Water percolating through the vadose zone reacts with the soil and aquifer sediments, which alters the concentrations of dissolved constituents. Dissolved minerals occur mainly in ionic or electrically charged forms. The major ions in groundwater are sodium (Na^{+}), magnesium (Mg^{+2}), calcium (Ca^{+2}), chloride (Cl^{-}), bicarbonate ($HCO3^{-}$), and sulfate ($SO4^{-2}$). Together, these major ions typically comprise more than 90 percent of the total dissolved solids of groundwater. The relative dominance of the major ions in water defines the character, or type of water, and is useful in evaluating whether water from separate areas or aquifers may have similar or different sources of origin (Poland & Evenson 1966).

Various systems for graphical presentation and for classifying water type have been developed. Most of these systems (i.e. bar graphs, pie diagrams, Stiff diagrams, and trilinear diagrams) compare the major dissolved ions in terms of milliequivalents per liter (meq/L), rather than the typical reporting standard of milligrams per liter (mg/L). Milliequivalent units are useful because they account for the mass and charge of the ions, which is important in water treatment and agricultural irrigation issues.

To determine the chemical character of groundwater, concentrations of the three major cations and the three major anions are first converted to milliequivalents. Any cation or anion with at least 1/3 or more of the respective milliequivalent totals becomes part of the chemical character name. By convention, cations are named first; for example, a water sample with 24 percent sodium, 30 percent magnesium, and 46 percent calcium cations, and 24 percent chloride, 13 percent sulfate, and 63 percent bicarbonate cations would be said to have a calcium-bicarbonate chemical character. A water sample with 42 percent sodium, 24 percent magnesium, and 35 percent calcium cations, and 23 percent chloride, 34 percent sulfate, and 43 percent bicarbonate cations would be said to have a sodium-calcium-bicarbonate-sulfate chemical character.

The major groundwater types that have been recognized throughout the San Joaquin Valley are as follows: east-side groundwater, west-side groundwater, and axial-trough groundwater. East-side groundwater is generally classified as calcium-bicarbonate in chemical nature, reflecting the quality of Sierra Nevada runoff waters in its relatively low TDS concentrations (typically less than 300 mg/L). East-side groundwater is the dominant water type within the District. West-side groundwater is typically sulfate dominated in chemical nature and generally highly mineralized, and only occurs in deposits associated with the Coast Ranges, and as such is not present within the study area. Axial-trough groundwater is essentially a blend of the east- and west-side groundwater types and is highly variable in chemical character. Axial-trough groundwater is only present in the extreme southwesterly portion of the study area (B&E 1972).

Another notable groundwater quality observation that was first documented by Mendenhall et al (1916) is that within the study area (and throughout the San Joaquin Valley) a relationship exists between groundwater quality and depth. More specifically, three vertical zones have been delineated based on groundwater quality. These zones from upper (better quality) to lower (poorer quality) are as follows: unconfined to semi-confined groundwater that is in nearly unrestricted hydraulic communication with the land surface, groundwater that is confined by the E-clay (Corcoran Clay) and/or other low permeability soil horizons, and brackish to saline connate to modified connate water underlying the majority of the San Joaquin Valley down to the crystalline basement complex rocks (USGS [Croft and Gordon], 1968).

5.3.2 Drinking Water

Drinking water standards are compared to a Maximum Contaminant Level (MCL) established by the California Department of Health Services, Code of Regulations, Title 22, Sections 64435 and 64473. Primary drinking water standards are established for chemical constituents with a potential toxic effect to humans when concentrations are above the MCL. Secondary drinking water standards are established for certain chemical constituents that may cause undesirable water characteristics, but that are not considered threats to human health.

5.3.3 Agricultural Irrigation

Irrigation-induced soil salinity is a continual threat to the sustainability of irrigated agriculture (Ayers, 1977 & Ayers & Westcott 1985). The physical conditions that often lead to excessive salt concentrations in soil include the following situations and processes:

- All irrigation water contains salts; therefore, the act of irrigation continually applies salts to the soil.
- Crops act as a mechanism that essentially extracts pure water, leaving salts behind.
- Without action taken to remove salts, they continue to become more concentrated, eventually reaching problematic levels in the soil.

Salts can cause several types of problems for irrigated agriculture, including:

- **Reduced Crop Yields**. Dissolved salts in the root zone of most crops create osmotic conditions that are additive to the soil matrix; the resulting force tends to reduce the water availability. In addition, excess salts may interfere with chemical reactions and reduce fertilizer uptake (Mass 1996). The potential for irrigation water to lead to reduced crop yields is indicated by the electrical conductivity (EC) of the water (expressed as deciSiemens per meter (dS/m) or millimhos per centimeter (mmhos/cm). The higher the EC, the more likely salts will create problematic conditions.

- **Soil Structure Problems**. The potential for soil structure problems depends on the type of soil and the type and balance of salts in the soil. A combination of an expansive clay soil, high levels of sodium salts in relation to calcium and magnesium in the soil, and a low-salt water can create soil structure problems. The result is low infiltration rates and a massive blocky soil that restricts root zone expansion. The common indicator for this type of problem is the sodium absorption ratio (SAR).

- **General Plant Toxicities**. The best-known salts with toxic effects are boron and sodium. However, high chloride levels can produce leaf burn if used with sprinklers (Hanson, Schwankl, and Fulton 1999).

5.4 SURFACE AND GROUNDWATER CONDITIONS

5.4.1 Historical Groundwater Quality Conditions

Historical groundwater quality throughout the study area has been documented by the previously referenced document prepared by B&E 1972, addressing water quality of the District from a broad perspective (i.e. a regional characterization). Due to gaps in the presently available data, the generalized groundwater quality data presented by B&E were used to document groundwater quality conditions at the time of the study (samples collected in the 1960's), and the limited recent groundwater quality data obtained during this study were compared to these earlier conditions. Plate 59 - Well and Surface Water Sample Location Map illustrates the locations of the groundwater wells used in this comparison and the locations of surface water samples.

Table 33 - Representative Chemical Analyses of Historical Groundwater Quality, was presented in B&E 1972, and represents general groundwater quality conditions at the time of sampling (1960).

Table 33. Representative Chemical Analyses of Historical Groundwater Quality
(in parts per million, except as shown)

Well No. Depth (Feet) Date	Hydrologic Unit No. II	Hydrologic Unit No. VI	Hydrologic Unit No. IV	Hydrologic Unit No. VI	Hydrologic Unit No. VI	Hydrologic Unit No. VI
	18S/R25E-27N1 334 3/8/60	20S/R22E-10H2 1,384 1/6/61	20S/R26E-7R1 580 6/19/62	19S/R22E-10A1 117 9/4/56	20S/R21E-3A1 44 5/16/62	20S/R21E-16M1 1,527 8/2/60
Mineral Constituent						
Calcium	21.0	2.0	20.0	112.0	42.0	6.0
Magnesium	2.0	0.0	12.0	11.0	19.0	2.0
Sodium	12.0	78.0	66.0	107.0	124.0	102.0
Bicarbonate	96.0	100.0	135.0	171.0	454.0	189.0
Sulfate	2.4	2.0	25.0	98.0	36.0	0.0
Chloride	4.0	66.0	80.0	235.0	26.0	67.0
Nitrate	1.0	1.5	7.4	0.9	0.5	0.0
Boron	-	0.5	-	0.0	0.0	0.4
Sodium (percent)	30	97	59	42	59	89
EC x 10^6 (Micromhos)	171	407	535	1,210	802	298
TDS (Sum)	107	234	314	674	501	542
Ground water type and aquifer source	East-side; Alluvial fan deposits	East-side; Continental deposits	East-side; Alluvial fan and continen-tal deposits	East-side; Shallow lake deposits	Axial - trough; Shallow lake deposits	Axial - trough; Lake and continental deposits

5.4.2 Recent Groundwater Quality Conditions

The groundwater data obtained from the various referenced sources investigated during this study was insufficient in both period of record and repeatability to graphically represent groundwater quality trends over time. However, data provided by Cal Water for four wells located near Visalia (18S/R22E-25Q1, 18S/R24E-27R2, 20S/R21E-3A1, and 19S/R25E-19E2) were utilized to prepare Stiff diagrams. Stiff diagrams graphically illustrate water quality by plotting the major cations and anions; the resulting shape of the diagram allows visual comparison of differences in water quality. As illustrated on the Stiff diagrams, groundwater quality in 18S/R24E-27R2, 20S/R21E-3A1, and 19S/R25E-19E2 is very similar during the time period plotted (1973 through 1984). Groundwater quality in 18S/R22E-25Q1 was much higher in sodium and potassium (cations) and marginally higher in chloride, bicarbonate, and sulfate (anions) during the time period plotted (1970). Plate 60 - Stiff Diagram Plots, illustrates representative Stiff diagrams for the four well referenced above.

For comparison to the B&E's Table VI-5 (presented above as Table 33), six wells (18S/R22E-25Q01, 18S/R24E-27R02, 18S/R25E-23C01, 20S/R21E-03A01, 19S/R25E-19E02, and 20S/R26E-07C01), were selected because they have the most comprehensive groundwater quality record of any of the wells identified during this study. Table 34 - Summary of Recent Groundwater Quality Analyses summarizes the results of these analyses, which range from 1961 through 1985.

5.4.3 Comparison of Historical and Recent Groundwater Quality Data

Due to the limited data presented in B&E's 1972 document and the limited more recent data available for this study, for comparison we averaged the concentrations for several key mineral constituents reported in B&E's Table VI-5, with the same mineral constituents from more recent chemical analyses. B&E's referenced table summarizes chemical analyses obtained from six wells (18/S/R25W-27N1, 20S/R22W-10H2, 20S/R26W-7R1, 19S/R22W-10A1, 20S/R21W-03A1, and 20S/R21W-16M1), between September 4, 1956 through June 19, 1962. The four wells used to represent more recent groundwater quality data included: 18S/R24E-27R2, 18S/R25E-23C1, 19S/R25E-19E2, and 19S/R25E-19E3, with these wells having been sampled between May 1984 and July 1985. Available data allowed comparison of the following mineral constituents: calcium, magnesium, sodium, sulfate, chloride, nitrate, and TDS.

The data presented by B&E for the time period between September 4, 1956 through June 19, 1962 for wells 18/S/R25W-27N1, 20S/R22W-10H2, 20S/R26W-7R1, 19S/R22W-10A1, 20S/R21W-03A1, and 20S/R21W-16M1 indicated an average calcium concentration of 40 milligrams per liter (mg/l); an average magnesium concentration of 9 mg/l, an average sodium concentration of 97 mg/l, an average sulfate concentration of 32 mg/l, an average chloride concentration of 95 mg/l, an average nitrate concentration of 2 mg/l, and an average TDS concentration of 474 mg/l.

Table 34. Summary of Recent Groundwater Quality Analyses

Well ID	Sample Date	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Boron (mg/l)	TDS	Electrical Conductivity
18S/R22E-25Q1	2/28/1961	--	--	192.0	--	87.0	--	0.04	--	1,190
18S/R22E-25Q1	4/16/1970	46.0	7.5	180.0	104.0	165.0	0.0	--	675	1,100
18S/R22E-25Q1	6/14/1978	49.0	6.3	180.0	120.0	148.0		0.10	676	1,110
18S/R22E-25Q1	5/24/1983	--	--	--	--	--	--	--	--	--
18S/R24E-27R2	5/17/1973	20.0	1.0	18.0	4.0	5.0	2.0		114	--
18S/R24E-27R2	5/15/1974	23.0	1.0	14.0	5.0	7.0	8.0	--	119	--
18S/R24E-27R2	4/19/1975	30.0	3.0	16.0	8.0	11.0	7.0	--	152	--
18S/R24E-27R2	4/20/1976	26.0	2.0	14.0	6.0	9.0	5.0	--	123	--
18S/R24E-27R2	3/1/1977	31.0	2.0	14.0	7.0	10.0	7.0	--	140	--
18S/R24E-27R2	6/27/1978	30.0	2.0	15.0	9.0	9.0	7.0	--	151	--
18S/R24E-27R2	6/4/1980	32.0	4.0	13.0	8.0	8.0	6.0	--	148	--
18S/R24E-27R2	6/8/1982	32.0	4.0	14.0	8.0	7.0	5.0	--	154	--
18S/R24E-27R2	5/15/1984	33.0	4.0	15.0	9.0	11.0	6.0	--	159	--
18S/R25E-23C1	9/29/1975	22.0	2.0	6.0	7.0	2.0	7.0	--	106	--
18S/R25E-23C1	8/18/1976	26.0	4.0	8.0	7.0	6.0	11.0	--	113	--
18S/R25E-23C1	8/24/1977	25.0	4.0	7.0	6.0	6.0	8.0	--	113	--
18S/R25E-23C1	6/27/1978	26.0	4.0	5.0	7.0	3.0	7.0	--	123	--
18S/R25E-23C1	8/11/1980	23.0	3.0	10.0	8.0	6.0	8.0	--	124	--
18S/R25E-23C1	1/12/1983	16.0	2.0	4.0	7.0	3.0	2.0	--	94	120
18S/R25E-23C1	7/17/1984	21.0	2.0	8.0	8.0	4.0	5.0	--	111	--
19S/R25E-19E2	10/7/1974	25.0	1.0	14.0	6.0	7.0	10.0	--	128	--
19S/R25E-19E2	2/4/1975	27.0	0.0	14.0	6.0	8.0	12.0	--	200	--
19S/R25E-19E2	2/19/1976	27.0	0.0	14.0	6.0	9.0	10.0	--	130	--
19S/R25E-19E2	3/30/1977	30.0	0.0	14.0	6.0	6.0	13.0	--	127	--
19S/R25E-19E2	10/3/1977	27.0	0.0	14.0	6.0	7.0	8.0	--	124	--
19S/R25E-19E2	2/7/1978	28.0	0.0	14.0	7.0	8.0	9.0	--	126	--
19S/R25E-19E2	5/6/1980	27.0	1.0	13.0	7.0	4.0	7.0	--	126	--
19S/R25E-19E2	2/9/1982	28.0	0.0	15.0	6.0	7.0	11.0	--	134	--
19S/R25E-19E2	5/15/1984	31.0	1.0	16.0	15.0	9.0	11.0	--	151	--
19S/R25E-19E3	4/17/1975	27.0	1.0	15.0	6.0	8.0	11.0	--	138	--
19S/R25E-19E3	7/27/1976	22.0	0.0	14.0	5.0	10.0	8.0	--	105	--
19S/R25E-19E3	10/4/1977	21.0	0.0	15.0	4.0	8.0	7.0	--	106	--
19S/R25E-19E3	7/19/1978	22.0	0.0	17.0	5.0	11.0	7.0	--	124	--
19S/R25E-19E3	2/26/1979	24.0	0.0	15.0	5.0	6.0	8.0	--	122	--
19S/R25E-19E3	6/18/1981	22.0	0.0	15.0	6.0	8.0	8.0	--	118	--
19S/R25E-19E3	5/9/1983	23.0	1.0	15.0	9.0	8.0	10.0	--	124	--
19S/R25E-19E3	7/25/1985	25.0	1.0	16.0	10.0	7.0	6.0	--	125	--
20S/R21E-03A1	5/16/1962	42.0	19.0	120.0	36.0	26.0	0.5	0.00	501	802
20S/R21E-03A1	12/9/1970	44.0	--	80.0	--	26.0	1.0	0.30		603
20S/R21E-03A1	6/14/1978	65.0	18.0	110.0	59.0	63.0		0.20	538	888
20S/R21E-03A1	5/24/1983	--	--	--	--	--	--	--	--	--
20S/R21E-03A1	5/24/1983	--	--	--	--	--	--	--	--	--
20S/R26E-07C1	9/17/1973	49.0	35.0	82.0	--	125.0	26.0	--	--	912
20S/R26E-07C1	1/31/1974	35.0	21.0	62.0	--	64.0	14.0	--	--	640

The more recent data available for the time period between May 1984 through July 1985 for wells 18S/R24E-27R2, 18S/R25E-23C1, 19S/R25E-19E2, and 19S/R25E-19E3 indicated an average calcium concentration of 27 mg/l, an average magnesium concentration of 2 mg/l, an average sodium concentration of 13 mg/l, an average sulfate concentration of 10 mg/l, an average chloride concentration of 7 mg/l, an average nitrate concentration of 7 mg/l, and an average TDS concentration of 111 mg/l.

Comparison of the averaged concentrations of the selected historical mineral constituents in groundwater with the more recent data indicates decreases in calcium, magnesium, sodium, sulfate, chloride, and TDS. The averaged nitrate concentration for the more recent time period (1984 through 1985) was slightly higher in comparison to the historical data set utilized.

5.4.4 Historical Surface Water Quality Conditions

Table 35 - Representative Chemical Analyses of Historical Surface Water Quality Available to District, was presented in B&E (1972), and represents general surface water quality conditions at the time of sampling (1960 through 1967).

Table 35. Representative Chemical Analyses of Historical Surface Water Quality Available to District
(in parts per million, except as shown)

Source	Kaweah River at Three Rivers		Kaweah River Below Terminus Dam	Kings River Below Peoples Weir	San Joaquin River at Friant Dam	Yokohl Creek	Dry Creek
Date	**5/16/67**	**9/11/67**	**9/11/67**	**9/15/67**	**5/8/67**	**2/4/60**	**2/4/60**
Mineral Constituent							
Calcium	8.4	12.0	9.5	4.0	5.0	29.0	29.0
Magnesium	0.0	1.5	1.2	1.0	0.4	7.7	6.4
Sodium	2.0	4.4	2.9	2.5	3.6	25.0	17.0
Bicarbonate	29.0	47.0	36.0	20.0	22.0	138.0	104.0
Sulfate	2.5	2.3	1.6	2.1	0.0	21.0	27.0
Chloride	0.0	2.9	1.7	1.6	1.4	16.0	15.0
Nitrate	0.6	0.8	0.5	0.6	1.0	0.9	3.3
Boron	0.0	0.0	0.0	0.1	0.0	0.1	0.1
Sodium (percent)	17	20	18	27	36	34	27
EC x 10^6 (Micromhos)	61	94	71	43	49	327	287
TDS (Sum)	28	48	36	23	23	213	182

Note: After B&E 1972

5.4.5 Recent Surface Water Quality Conditions

A comparison of historical and recent surface water quality data was attempted; however the locations of the historical surface water samples are outside the District boundaries (illustrated on Plate 59) precluded a useful comparison. Table 36 - Representative Analysis of Recent (1973-1985) Surface Water, summarizes more recent (i.e. 1973 through 1985) surface water quality conditions.

Table 36. Representative Analysis of Recent (1973-1985) Surface Water

Sample I.D.	Sample Date	Constituent	Result
C2817000	14-Feb-73	Specific Conductance (umhos/CM @ 25C)	198
C2817000	14-Feb-73	pH, Lab, Standard Units (Su)	7.20
C2817000	14-Feb-73	Alkalinity, Total (mg/L as $Caco_3$)	71.0
C2817000	14-Feb-73	Calcium, Dissolved (mg/L as Ca)	20.0
C2817000	14-Feb-73	Sodium, Dissolved (mg/L as Na)	12.0
C2817000	14-Feb-73	Chloride, Dissolved In Water (mg/L)	7.30
C2817000	14-Feb-73	Boron, Dissolved (ug/L as B)	100
C2817000	14-Feb-73	Nitrate Nitrogen, Dissolved (mg/L as NO_3)	4.60
18S/25E-19M01 M	25-Jul-77	Temperature, Water (Degrees Fahrenheit)	66.0
18S/25E-19M01 M	24-Feb-84	Specific Conductance (umhos/cm @ 25C)	194
18S/25E-19M01 M	24-Feb-84	pH, Lab, Standard Units (Su)	8
18S/25E-19M01 M	24-Feb-84	Calcium, Dissolved (mg/L as Ca)	22
18S/25E-19M01 M	24-Feb-84	Sodium, Dissolved (mg/L as Na)	14
18S/25E-19M01 M	24-Feb-84	Potassium, Dissolved (mg/L as K)	0.9
18S/25E-19M01 M	24-Feb-84	Chloride, Dissolved In Water (mg/L)	5
18S/25E-19M01 M	24-Feb-84	Sulfate, Dissolved (mg/L as SO_4)	6
18S/25E-19M01 M	24-Feb-84	Nitrate Nitrogen, Dissolved (mg/L as NO_3)	5

5.5 DISCUSSION

5.5.1 Groundwater

Although limited groundwater data were available, some general comparisons of groundwater quality during the 1960s (after B&E) with data representing the mid-1980s can be made. In addition, Stiff diagrams were prepared from data provided by DWR and Cal Water that is representative of the general groundwater quality in the immediate vicinity of Visalia at specific time periods (noted on the plots). Overall, however, the available groundwater quality data were found to be insufficient in both period of record and consistency for this study and as such, was a limiting factor. Several agencies were found to maintain various groundwater quality databases, however virtually none of the data represented a significant period of record, nor was there found to be consistency of analyses. Further compounding the lack of data were various administrative difficulties in data procurement.

5.5.2 Surface Water

Comparison of historical and more recent surface water quality data was attempted. The locations of the historical water quality data were all outside of the District boundaries, and the locations of the more recent surface water quality data were mostly inside the District boundaries. Comparison of these data could not be completed because the large geographic difference between data points does not allow direct correlation of constituents. More specifically, because the historical and more recent surface water quality data points were not in close proximity, variations in concentrations could be caused by a wide range of factors (i.e. different soil types, different origin, point source contaminates, etc.).

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CHAPTER 6 - WATER BALANCE AND SAFE YIELD

6.1 INTRODUCTION

Presented in Chapter 6 is analysis and tabulation of the components of water supply, use, and disposal over the established base period and estimates of the annual water supply surplus or deficiency for each hydrologic unit and for the District as a whole. Given the availability of data and uncertainties in accuracy in calculating the magnitude of each of these components, the annual totals were in turn compared to the annual changes of groundwater in storage in the District, as determined by the specific yield method that was documented in Chapter 3.

6.2 HYDROLOGIC BUDGET

6.2.1 General Statement

A hydrologic budget is simply a quantitative statement of the balance of the total water gains and losses from a basin or defined area for a given period of time. The given period of time, or base period, is representative of long-term average conditions of precipitation and surface water availability. The major components of the budget or balance evaluated for the District can be expressed by the following relationship.

$$P + S_I + Sb_I + PR + W + AR = GP + Sb_o + EP + EL + EW \pm \Delta S$$

Where:
- P = Percolation of Precipitation
- S_I = Streambed Percolation and Surface Water Delivery Conveyance losses
- Sb_I = Subsurface Inflow
- PR = Percolation of Applied Irrigation Water
- W = percolation of Wastewater
- AR = Artificial Recharge
- GP = Gross Groundwater Pumpage
- Sb_o = Subsurface Outflow
- EP = Extraction by Phreatophytes
- EL = Evaporative Losses
- EW = Exported Water
- ΔS = Change of Groundwater in Storage

The hydrogeologic base period for the study was presented in Chapter 1 and encompasses the years from 1981 through 1999 (19 years). Selection of this base period was sensitive to the issues of historic wet-dry cycles, approximation of average precipitation conditions and deliveries of surface water throughout the District, and avoidance of significant volumes of water in transit to the zone of saturation at either the beginning or end of the base period. In any water balance study, there are assumptions in estimating the seasonal volumes of recharge (inflow) or discharge (outflow). The assumptions used in calculating the magnitude of the seasonal amounts of recharge and discharge are explicitly stated in this report. For all of the inflow and outflow components, the time period used has a caledar year, between January 1 and December 31 of each year.

The hydrologic processes of inflow and outflow to the groundwater reservoir are graphically shown on Figure 4 - Conceptual Model of Hydrologic Processes, and are summarized in Table 37 - Hydrologic Processes Considered in the Hydrologic Budget.

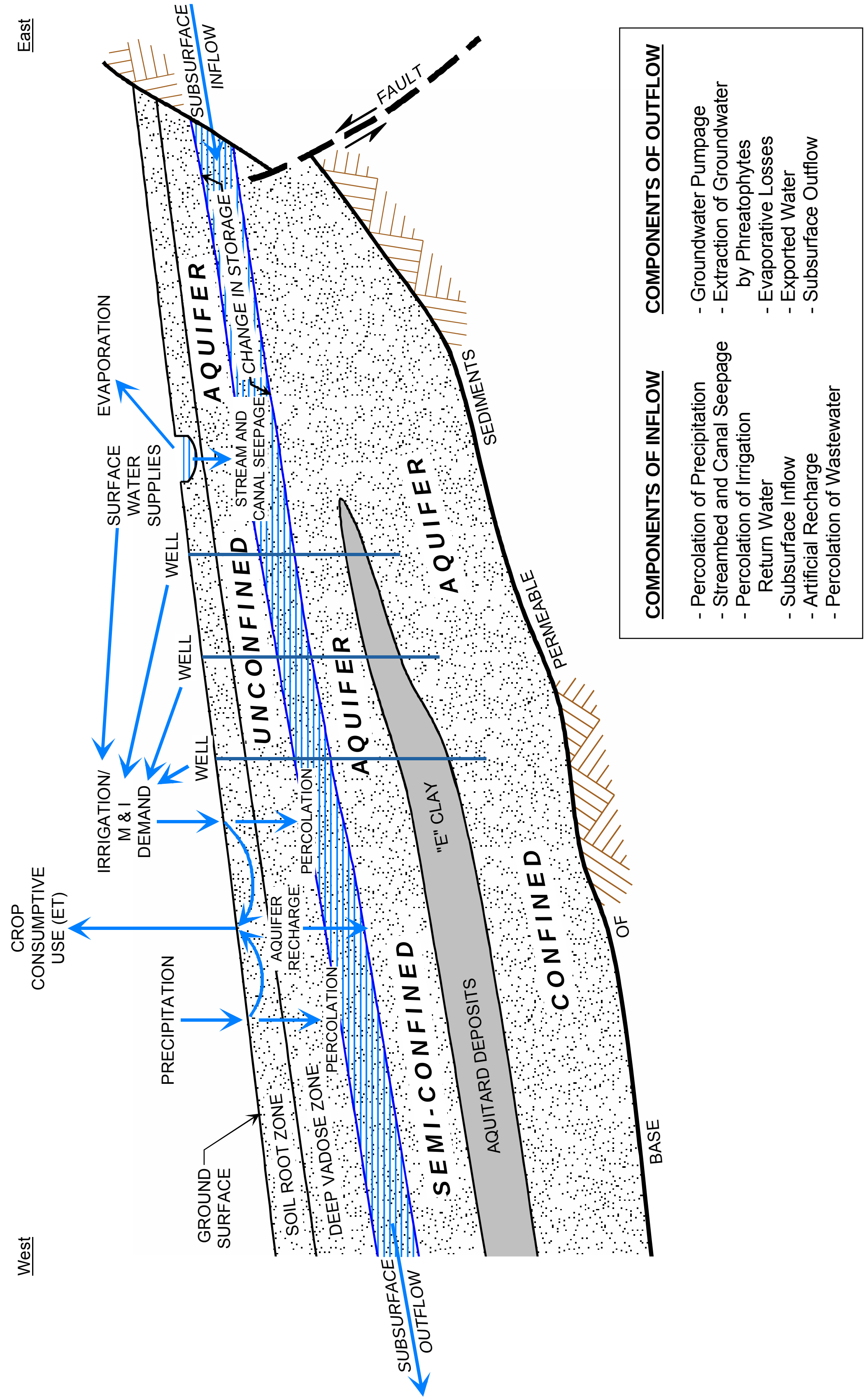

Figure 4. Conceptual Model of Hydrologic Processes

Table 37. Hydrologic Processes Considered in the Hydrologic Budget

	Inflows	Outflows	Δ Storage
LAND SURFACE	• Precipitation	• Evaporation (assumed negligible) • Infiltration to soil root zone • Overland runoff (assumed negligible)	
	• Stream and canal inflows ➢ Natural runoff ➢ Surface water imports ➢ Surface water deliveries	• Stream and canal inflows ➢ Natural runoff ➢ Surface water exports • Diversions and deliveries ➢ Deliveries to districts ➢ Deliveries to farmers • Seepage (direct aquifer recharge) • Evaporation	• Surface water channel storage (assumed negligible)
	• Irrigation Applications ➢ Surface water deliveries ➢ Pumped groundwater	• Infiltration to soil root zone (accounted for in irrigation efficiency) • Runoff (assumed negligible)	
SOIL ROOT ZONE	• Infiltration from: ➢ Precipitation ➢ Irrigation applications	• Evapotranspiration (crop water use) • Deep percolation	• Soil moisture storage change
DEEP VADOSE ZONE	• Deep percolation	• Aquifer recharge	• Deep vadose zone moisture storage change
SATURATED ZONE	• Aquifer recharge ➢ Stream and canal seepage ➢ Vadose zone percolation ➢ Subsurface Inflow	• Groundwater pumping • Subsurface outflow • Consumptive use by Phreatophytes • Groundwater exports	• Groundwater storage change

Source: Naugle (2001), with modifications

6.2.2 Components of Inflow

6.2.2.1 Subsurface Inflow

Subsurface groundwater inflow occurs across the District boundaries and hydrologic units in accordance with the hydraulic gradient and permeability of the materials. The methodology used and the annual estimation of such volumes of inflow is provided in Chapter 3. Groundwater in unconfined aquifers moves in response to the slope of its surface, and the direction of flow is perpendicular to the contour lines shown on groundwater level contour maps. The rate of flow is a function of the slope of the groundwater surface and the permeability of the water-bearing materials. Rates of flow on the order of a few feet per day are common, although in materials of low permeability, such rates may be reduced to on the order of a few feet per year. Flow of groundwater in confined aquifers is analogous to the flow of water in a pressure conduit. Groundwater movement is induced as a result of head differentials created by pumping from the confined aquifer or by a buildup in the water table in the unconfined groundwater body supplying the aquifer (in this case on the east side of the District).

The water level elevation contour maps (Plates 32 to 38) show the general direction of movement of groundwater in the various aquifer systems within the District and where subsurface inflow (and outflow) occurs both to and from the District. A discussion of the general flow patterns over the base period was provided in Chapter 3. The principal direction of groundwater flow is to the southwest parallel to the major axis of the District. Unconfined groundwater in the Kaweah River alluvial fan and continental deposits moves in this direction through Hydrologic Unit Nos. I to V, as a typical lobe of recharge.

The influence of water supply from the Kings River also occurs to lands generally west of the District and can be seen by water level contours that reflect replenishment by river and canal seepage losses in these westerly hydrologic units. They also show the pumping depressions, which have been created in Hydrologic Unit No. VI north of Corcoran and, to a lesser extent, west of Visalia.

A typical map showing the subsurface reaches and magnitudes of flow (in afy) for the Spring 1999 water level data is shown on Plate 49 - Typical Map of Subsurface Flow Calculation. Similar maps were prepared for each year of the base period and a routine prepared in Geographic Information System (GIS) to solve the standard D'Arcy equation for each reach considered. A summary of the subsurface inflow estimates to the District and for each hydrologic unit during the 19-year base period is presented on Table 38 - Summary of Subsurface Groundwater Inflow Volumes. The data in Table 38 indicate that for the entire District, over the base period, there was an average annual net inflow across (into) District perimeter boundaries of about 55,600 af. Inflow in the District was about 10,500 afy into Hydrologic Unit No. II and from about 15,000 to 30,000 afy into Units I, III, IV, V, and VI. Table 38 also presents net inflow and outflow volumes for each unit for each year of the base period. Average annual inflows varied from about 35,900 af (1988) to 87,000 af (1984).

Table 38. Summary of Subsurface Groundwater Inflow Volumes
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	District Inflow	District Outflow	District Net
1981	13,240	9,532	18,704	26,698	29,341	43,891	73,596	46,214	27,382
1982	11,850	7,658	20,691	33,573	25,477	55,124	64,523	32,159	32,364
1983	13,453	7,314	23,451	38,230	24,776	44,521	61,820	48,858	12,962
1984	11,734	7,741	33,691	74,114	22,467	31,327	86,961	38,720	48,241
1985	8,786	10,386	15,306	36,234	15,525	26,319	47,110	16,120	30,990
1986	11,388	6,576	20,392	39,331	15,364	34,943	45,126	24,753	20,373
1987	18,025	7,441	14,121	39,882	14,126	31,141	54,288	8,776	45,512
1988	18,893	9,633	9,425	14,179	19,546	16,752	35,884	12,509	23,375
1989	15,278	9,504	16,378	7,923	18,143	17,287	36,796	23,012	13,784
1990	20,531	9,260	12,881	21,065	17,471	26,544	53,527	11,891	41,636
1991	17,233	10,388	12,056	21,697	25,183	31,992	59,906	18,111	41,795
1992	22,389	11,410	7,766	40,046	30,643	13,596	62,895	9,334	53,561
1993	12,736	10,641	13,425	34,899	20,110	30,041	48,130	13,806	34,324
1994	8,611	13,205	9,159	26,858	31,474	21,846	36,643	13,321	23,322
1995	15,660	23,327	7,418	15,864	32,611	35,988	59,813	12,445	47,368
1996	26,792	6,347	17,096	31,846	17,014	32,408	71,533	35,147	36,386
1997	18,902	14,327	33,801	44,494	9,797	28,419	68,574	50,716	17,858
1998	16,511	13,063	21,858	40,488	22,239	21,960	49,156	24,890	24,266
1999	15,702	10,935	13,324	20,118	29,782	21,989	39,534	32,363	7,171
Maximum	**26,792**	**23,327**	**33,801**	**74,114**	**32,611**	**55,124**	**86,961**	**50,716**	**53,561**
Minimum	**8,611**	**6,347**	**7,418**	**7,923**	**9,797**	**13,596**	**35,884**	**8,776**	**7,171**
Average	**15,669**	**10,457**	**16,892**	**31,976**	**22,163**	**29,794**	**55,569**	**24,902**	**30,667**

Comparison of the subsurface groundwater flow volumes shown in Table 38 to those calculated by B&E (1972) is of interest. The hydrologic unit boundaries are for the most part substantially different, although some reaches are similar. The volume of average annual subsurface inflow calculated by B&E is stated at about 7,900 af and was assumed to be constant in each year of this base period for purposes of analysis. Presumably, the inflow number of B&E is a "net" inflow after consideration of subsurface outflow. This volume is nearly an order of magnitude less than the volume calculated in this study (net subsurface inflow estimated at 30,667 afy). The difference presumably is in the method of analysis used and declining water levels in the west side of the District which resulted in increased hydraulic gradients toward pumping depressions, and correspondingly greater volumes of subsurface inflow.

6.2.2.2 Percolation of Precipitation

The amount of precipitation that percolates downward to aquifers in a groundwater basin can vary considerably, depending upon the type and structure of soil, density of vegetation, the quantity, intensity and duration of rainfall, the vertical permeability of the soil, and topography. Much of the infiltrating rainfall is held within the root zone because at the beginning of each rainy season there is an initial deficiency of soil moisture. During the summer months, the capillary soil moisture is more or less completely depleted from the soil within the root zone by the processes of evaporation and transpiration. No deep percolation of rainfall typically occurs until the initial soil moisture deficiency is exceeded. In some areas, many years may pass before significant quantities of rainfall penetrate beyond the root zone of native vegetation. In irrigated soils, because of the artificial application of water, the initial Fall moisture content is greater, and less annual rainfall is required to meet the soil moisture deficiency. Once the soil moisture deficiency within the root zone has been satisfied, the excess precipitation will percolate downward until it eventually reaches the groundwater reservoir.

There are two primary considerations in estimating the volume of precipitation that percolates beyond the root zone and contributes to groundwater in storage. First, a determination of deep percolation of rainfall in inches for various vegetative covers is required, and, second, determination of the total area of the various covers for which inches of percolation is necessary. The total volume of percolation is then calculated (i.e., inches of percolation x acreage).

A precise field measurement of the amount of rainfall that percolates below the root zone and reaches the groundwater reservoir requires special equipment, is time consuming, and, to be of value, must be continued over many years and under a variety of conditions. Estimates of the amount of rainfall that percolates to the aquifers in the District could be approached by using empirical measurements of percolation of rainfall made by Blaney (1933) in Ventura County. The Blaney (1933) investigation has become a convenient procedure for calculation of deep percolation of rainfall, particularly in areas where there is a general lack of soil type data, precipitation station coverage and California Irrigation Management Information System (CIMIS) station reference evapotranspiration (ET_o) data. Evapotranspiration is discussed more thoroughly later in this chapter.

For the District, however, which is relatively flat, with known crop types, with good rainfall distribution and CIMIS (ET_o) data, and relatively good soil data, percolation of rainfall was evaluated directly by developing a monthly moisture model spreadsheet that accounted for immediate evaporation, effective rainfall, percolation of infiltrated rainfall, and percolation of rainfall runoff. These terms are defined as follows:

- Immediate evaporation - evaporation that occurs from plant or soil surfaces within the first 3 days after a rainfall.
- Effective rainfall - rainfall that remains stored in the rootzone for later use by crops.

- Percolation of infiltrated rainfall - rainfall which infiltrates that is in excess of the storage capacity of the rootzone.
- Percolation of rainfall runoff - it is assumed that no surface runoff occurs between the hydrologic units or off the District boundaries, and any rainfall that results in surface runoff ultimately becomes percolated water in the receiving river or canal. Specific spill points of surface water are, however, considered in the analyses of surface water (Chapter 4). Evaporation from free water surfaces after rainfall becomes runoff is not considered, such as would be stored in artificial recharge basins or from river or distributary canals.

In the analysis, certain assumptions were made concerning soil characteristics in each of the six hydrologic units. Two very old soil surveys were available for the study area (U.S. Department of Agriculture, 1938). These references provide reliable maps of soil distribution and estimates of field capacity for the soils in the area. An examination of the soils maps in each of these surveys indicated a wide range of soils in the District. Table 39 - Assumed Soil Properties for Hydrologic Units, lists the major soil types in each hydrologic unit and the assumed average field capacity. The assumed available water holding capacity is 70 percent of the assumed field capacity. The available storage for off-season rainfall is assumed to be 60 percent of the available water holding capacity over a 4-foot rootzone.

Table 39. Assumed Soil Properties for Hydrologic Units

Hydrologic Unit	Predominate Soil Types*	Field Capacity (in/foot)	Assumed Available Water Holding Capacity (in/foot)	Assumed Available Off-Season Water Storage Available (inches)	Assumed % of Rainfall Immediately Infiltrating Irrigated Acreage (%)
1	Hanford Fine Sandy Loam Foster Sandy Loam Madera Sandy Loam	1.50	1.05	2.52	65
2	San Joaquin Loam Madera Loam Arnold Sandy Loam Fresno Sandy Loam	2.65	1.85	4.44	60
3	Arnold Sandy Loam Foster Sandy Loam Hanford Fine Sandy Loam Fresno Fine Sandy Loam	2.00	1.4	3.36	60
4	Madera Clay Madera Loam Fresno Loam Arnold Sandy Loam Foster Sandy Loam	2.25	1.60	3.84	60
5	Chino/Foster Loam Arnold Sandy Loam Merced Loam Fresno/Merced Loam	2.5	1.75	4.2	55
6	Grangeville Sandy Loam Chino Clay Chino Loam Hacienda Sandy Loam	3.0	2.1	5.04	50

Immediate evaporation of rainfall is considered that amount that evaporates from plant or soil surfaces during the last day of the event and each of the 2 days thereafter. It is assumed that the evaporation rates for these 3 days are 100%, 80%, and 30% of daily ET_o respectively. It was further assumed that there would be two events per month. Thus, immediate evaporation was 4.2 times the average daily ET_o for any month there was rainfall. If this number was greater than the gross rainfall for that month, then no rainfall was considered effective or as percolation to groundwater.

Immediate Evaporation = 4.2 x ET_o avg. [I]

Where:

Immediate Evaporation = evaporation losses of gross rainfall for the month
ET_o avg. = average daily ET_o for the month

Different calculations were then used to estimate effective rainfall in-season (when a crop was growing on the field) versus off-season. Column 5 of Table 39 above shows the assumed soil moisture storage available for off-season rainfall. Column 6 of Table 39 indicates the percentage of gross rainfall that is assumed to infiltrate the soil.

Thus, rainfall in the off-season was partitioned as follows:

1. Immediate evaporation was estimated and subtracted from the gross as previously described using equation [I]
2. The percentage infiltrated was then estimated using the number in column 6 of Table 39. That is:

   Infiltrated Rainfall = Column 6 x Adjusted Gross Rainfall [II]

   Where:

   Infiltrated Rainfall = rainfall that infiltrates on a field

   Column 6 = assumed percentage infiltrated as per Table 39 (as a percentage)

   Adjusted Gross Rainfall = gross monthly rainfall minus Immediate Evaporation as determined by Equation [I]
3. Infiltrated rainfall was summed as effective rainfall until the estimated inches of infiltrated rainfall exceeded the number in Column 5 of Table 39. Thereafter, the estimated infiltrated rainfall was assumed to be percolation of rainfall to the ground water aquifer.

   Percolated Rainfallfield/off-season = ∑ (Infiltrated Rainfall-Available Storage)off-season [III]

   Where:

   Percolated Rainfallfield/off-season = percolation of rainfall below the rootzone on the field during the off-season- but no less than 0

   Infiltrated Rainfall is rainfall infiltrating the field as per equation [II]

   Available Storage is Column 5 of Table 39.

∑ implies a summation of rainfall events in the off-season

4. All gross rainfall that was not estimated as immediate evaporation, effective (stored in the rootzone as per Column 5 of Table 39), or percolation of infiltrated water on the field was assumed to be surface runoff of rainfall that became percolation to the ground water.

Percolated Rainfalloff-field/off-season = ∑ (Gross Rainfall -

(Immediate Evaporation + Infiltrated Rainfall)) off-season [IV]

Where:

Percolated Rainfalloff-field/off-season = percolation of rainfall below the rootzone off the field during the off-season

Gross Rainfall = recorded gross rainfall

Immediate Evaporation - as determined by equation [I]

Infiltrated Rainfall - as determined by equation [II]

∑ implies a summation of rainfall events in the off-season

Effective Rainfall In-Season was estimated using the relationships listed in Table 40 - Average Monthly Effective Rainfall in Inches as Related to Monthly Gross Rainfall and Monthly Crop Evapotranspiration, between gross rainfall, crop water use, and resulting effective rainfall. The information in Table 40 is taken from the U.S. Natural Resources Conservation Service National Engineering Handbook, Chapter 2 ([NEH-2], 1993). However, for this study, the estimated immediate evaporation was subtracted out first. Also, the amount of monthly effective rainfall was constrained by the monthly crop water use (ETc). Any rainfall not considered immediate evaporation or effective rainfall, was considered percolation of rainfall off the field.

Table 40. Average Monthly Effective Rainfall in Inches as Related to Monthly Gross Rainfall and Monthly Crop Evapotranspiration

Monthly ETc (in.)	Gross Monthly Rainfall (inches)																
	0	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
0.0	0.00	0.28	0.59	0.87	1.14	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39
1.0	0.00	0.30	0.63	0.93	1.21	1.47	1.73	1.98	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23
2.0	0.00	0.32	0.66	0.98	1.27	1.56	1.83	2.10	2.36	2.61	2.86	3.10	3.10	3.10	3.10	3.10	3.10
3.0	0.00	0.34	0.70	1.03	1.35	1.65	1.94	2.22	2.49	2.76	3.02	3.28	3.53	3.79	4.03	4.03	4.03
4.0	0.00	0.36	0.74	1.09	1.43	1.74	2.05	2.35	2.63	2.92	3.20	3.47	3.74	4.00	4.26	4.52	4.78
5.0	0.00	0.38	0.78	1.16	1.51	1.84	2.17	2.48	2.79	3.00	3.38	3.67	3.95	4.23	4.51	4.78	5.05
6.0	0.00	0.40	0.83	1.22	1.59	1.95	2.29	2.62	2.95	3.26	3.57	3.88	4.18	4.48	4.77	5.06	5.34
7.0	0.00	0.42	0.88	1.29	1.69	2.06	2.42	2.77	3.12	3.45	3.78	4.10	4.42	4.73	5.04	5.35	5.65
8.0	0.00	0.45	0.93	1.37	1.78	2.18	2.56	2.93	3.29	3.65	4.00	4.34	4.67	5.00	5.33	5.65	5.97
9.0	0.00	0.47	0.98	1.45	1.88	2.30	2.71	3.10	3.48	3.86	4.23	4.50	4.94	5.29	5.64	5.98	6.32
10.0	0.00	0.50	1.00	1.50	1.99	2.44	2.86	3.28	3.68	4.08	4.47	4.85	5.23	5.60	5.96	6.32	6.68

It should be noted that for the majority of crops grown in the District, any rainfall that occurs during the growing season is minimal. Thus, errors in the total water budget that are introduced in any process to partition gross rainfall that falls in season are minimal.

Based on the data presented in Tables 39 and 40 and the above equations, percolation of rainfall in the District over the base period averaged about 96,200 afy and ranged from a high of about 275,000 afy in 1998 (a so-called "El Niño" event) to a low of about 22,300 afy in 1984. Volumes calculated for each hydrologic unit for each year of the base period are presented in Table 41 - Summary of Annual Volumes of Deep Percolation of Rainfall. Percolation of rainfall was (in a gross sense) about the same in Hydrologic Unit Nos. IV, V, and VI, which are the largest hydrologic units in the District. Normalized on a per-acre basis over the entire District, percolation of rainfall averaged about 0.28 afy, or about 3.4 inches per year. "Average" rainfall in the District over the base period was 10.9 inches. Obviously, deep percolation of rainfall can be quite episodic.

Table 41. Summary of Annual Volumes of Deep Percolation of Rainfall
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. 1	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	3,870	9,472	5,949	15,401	13,082	12,289	**60,062**
1982	5,302	12,347	7,143	19,087	16,837	15,805	**76,521**
1983	8,875	25,175	14,982	35,716	32,971	31,805	**149,523**
1984	2,505	2,780	1,149	5,279	4,019	6,546	**22,277**
1985	4,969	10,619	5,317	14,096	11,093	9,828	**55,922**
1986	8,095	20,916	11,945	29,187	22,197	20,743	**113,083**
1987	4,691	14,727	8,526	18,285	15,764	15,860	**77,853**
1988	2,338	7,419	4,016	10,851	10,867	11,356	**46,848**
1989	2,638	9,003	4,884	13,208	13,250	10,766	**53,749**
1990	4,246	10,467	5,564	14,995	13,944	14,624	**63,841**
1991	5,502	12,855	7,378	22,136	18,251	17,291	**83,412**
1992	3,604	8,147	4,792	14,774	13,497	13,802	**58,616**
1993	8,222	22,619	12,756	32,961	29,454	28,687	**134,701**
1994	4,118	9,802	4,992	12,792	13,612	15,725	**61,043**
1995	13,447	29,480	15,418	43,517	36,312	33,992	**172,165**
1996	7,592	17,868	9,460	25,632	20,657	21,697	**102,905**
1997	7,257	14,264	7,838	21,387	17,089	15,777	**83,612**
1998	21,073	46,371	23,078	69,961	60,200	54,330	**275,012**
1999	10,684	21,255	11,619	37,415	27,929	27,995	**136,898**
Maximum	21,073	46,371	23,078	69,961	60,200	54,330	**275,012**
Minimum	2,338	2,780	1,149	5,279	4,019	6,546	**22,277**
Average	6,791	16,083	8,779	24,036	20,580	19,943	**96,213**

Comparison of deep percolation of rainfall calculated in this study (about 96,200 afy over the 1981 to 1999 base period) to that considered by B&E (1972) cannot be performed. B&E approached the analysis by examining annual precipitation data in and surrounding the District and developing a relationship of annual rainfall for each hydrologic unit to that which occurred at the Visalia precipitation station. The period considered was (water years) 1962 to 1966. They then defined "effective precipitation" as that portion of annual precipitation available to meet crop moisture requirements or deep percolation to groundwater. The definition is confusing. How effective precipitation was calculated is not presented. It appears that the annual depth of effective precipitation at each station was determined by "subtracting up to one-half inch per month from the recorded precipitation in those months when precipitation occurred." While there may be some rationale for this, the approach seems arbitrary. Nonetheless, this method was then applied to a longer 32-year base period and an average annual volume of effective precipitation was estimated at 161,400 af (B&E, Table V-2). A breakdown by hydrologic unit (different from the hydrologic units used in this study) was also provided. This estimated average annual value of effective rainfall advanced by B&E is about 6 inches per year. The amount is not partitioned into effective rainfall and deep percolation of rainfall. Coincidentally, the total effective rainfall for the District as calculated in this study over the base period is about 70,700 afy (refer to Table 52).

Later in their report, B&E mentions that direct estimates of deep percolation of precipitation were not made in connection with their investigation. They state that such deep percolation occurs only in infrequent years of abnormally high precipitation. The total magnitude of the contribution to groundwater "from this source" is probably no more than a few thousand afy on the average. We disagree with this conclusion.

The study by Naugle (2001) of the adjacent Tule Basin area provides an additional reference of the relative contribution of annual quantities of precipitation and irrigation return flow for that similarly cropped but larger area (irrigated agriculture of about 385,000 acres). Although the model used in that study did not distinguish between percolation by precipitation and applied irrigation water, the average annual combined total was about 190,000 af, which, on a unit basis, is less than the average annual quantities estimated in this study, about 298,000 afy (both percolation of precipitation and percolation of applied irrigation water). It should be noted that average annual precipitation in the Tule Basin is about 30 percent less than in the District.

6.2.2.3 Streambed Percolation and Delivered Water Conveyance Losses

The methods used to estimate seepage losses in the Lower Kaweah and St. Johns Rivers were presented in Chapter 4. As indicated in Table 22 - Summary of Conveyance Losses, Lower Kaweah and St. Johns River Systems, annual conveyance losses associated with the Lower Kaweah and St. Johns River Systems ranged from about 31,200 (1990) to 164,800 (1983) and averaged about 79,500 afy over the base period. These systems do not traverse Hydrologic Unit No. V. Most of the conveyance losses from these systems occurred within Hydrologic Unit No. II. Notable losses occurred during the water years of 1983 and 1998.

The methods used to estimate seepage losses in the constructed channels were presented in Chapter 4. Based on the developed loss percentages, a summary of the estimated annual quantities of conveyance losses within each hydrologic unit related to the channel systems is tabulated in Table 26 - Summary of Ditch Systems Conveyance Losses. Average losses in the constructed channels (ditches) were on the order of 128,700 afy over the base period. These data are, in turn, combined with the conveyance losses related to the Lower Kaweah and St. Johns River systems (Table 22) as Table 27 - Summary of All Delivered Water Conveyance Losses. As indicated, average annual losses within the District are estimated at about 208,100 afy and ranged from a high of about 433,000 af in 1983 to a low of about 49,000 af in 1990.

6.2.2.4 Artificial Recharge

6.2.2.4.1 General Characteristics

As discussed in Chapter 4, since the 1930s, the District has operated groundwater recharge ("sinking") basins for purposes of conserving available water supply and flood control within the District. Information on the history of the development, operations, size, location, approximate diversions, maintenance, and other features of each recharge basin are available from the District in various forms and have been summarized in Chapter 4.

The District presently operates about 40 recharge basins with a combined surface area of about 2,100 acres. B&E (1972, pg. VI-16) provided a brief summary of District recharge activities as of about 1970. At that time, there were about 36 recharge basins both in and immediately adjacent the District, covering some 4,600 acres, with an estimated recharge capacity of 1,100 af per day. Total volumes of annual average recharge to the District was not directly provided by B&E.

Recharge basins in the District serve to supplement natural replacement to the groundwater reservoir and channel loss contributions. Although the source of supply for each recharge basin is variable from year to year, the approximate quantities of artificial recharge can be estimated for each year of the base period for each hydrologic unit. It should be noted that treated wastewater from the City of Visalia, which is in excess of irrigation demand, is intermittently directed to an adjacent recharge basin. Tabulation and accounting of inflows depends on the accuracy of data relating to the number of days per year of wetted area in each basin and the hydraulic conductivity or percolation capacity of the basin, typically expressed in units of gallons per day per square foot or in af per day per acre.

6.2.2.4.2 Record Data

Record data and method used to estimate artificial recharge in the District were presented in Chapter 4.

6.2.2.4.3 Data Analyses

Average annual inflow is on the order of 65,700 af and ranged from a high of about 304,000 afy in 1983 to a low of 69 afy in 1990. By comparison, B&E (1972) estimated a total artificial recharge infiltration capacity in the District of about 1,114 af per day (conditions prevalent in the late 1960s), but did not provide an actual estimate of the annual volumes for their 5-year base period (1962 to 1966). The results of the analysis are presented in Table 29 - Summary of Recharge Basin Inflow.

6.2.2.5 Percolation of Irrigation Return Water

Percolation of irrigation return water (derived from either ground or surface water [refer to Figure 4]) in the District is dependent on a variety of factors including crop type, irrigation efficiency, climate factors, irrigation management practices, and soil types. Gross required applied irrigation water for the irrigated acreages in the District by crop type and in each hydrologic unit has been calculated for each year of the base period. The results of this analysis are presented in Section 6.2.3.2 of this report. Gross required applied irrigation water is an estimate of applied water considering net crop water use, effective rainfall, losses due to conveyance and frost control (if present), irrigation efficiency, and required leaching for salinity control. The term "irrigation efficiency" accounts for required applications in excess of net consumptive uses due to system design, maintenance, and scheduling (frequency and duration of irrigations). Losses due to irrigation efficiency are normally considered distinct from losses due to require leaching (percolation of water below the root zone) to maintain a salt balance in the root zone. This required leaching, as excess applied irrigation water, is a theoretical component of recharge. Depending on land use group and type of irrigation (e.g., sprinkler vs. furrow), the leaching ratios (percolation below the root zone) can range from about 2 to 16 percent (Hanson, 1999). For drip irrigation, deep percolation likely ranges from 10 to 15 percent of the applied water (Hanson, 1999). For flood and furrow irrigation, however, deep percolation of applied irrigation water can be as high as 30 percent. Due to the amount of rainfall, types and general management practices of the irrigation systems in use, and types of crops grown, required leaching ratios are likely very low in the District (i.e., less than 5 percent).

Irrigation Return Flows are thus calculated as the Gross Required Applied Irrigation Water minus Total Consumptive Use, and are presented in Table 42 - Percolation of Irrigation Return Water. Note that total consumptive use is equal to net crop water use (evapotranspiration) *plus* evaporative conveyance losses *plus* immediate soil and crop surface evaporation during irrigations *minus* effective rainfall. As such, it is approximately equal to total applied irrigation water less total crop ET_o.

As indicated in Table 42, the average percentage of percolation of irrigation return water calculated in the study for the 19-year base period was about 179,300 afy, or about 22 percent, of the average annual total applied irrigation water total of 809,000 afy.

Percolation of irrigation return water was not explicitly discussed by B&E (1972) other than to suggest (page III-6) that "of the total water applied for irrigation, about 65 percent is consumptively used." Presumably, the 65 percent consumptively used is the crop water demand and immediate evaporation with the balance, 35 percent, being what we in this study define as percolation of irrigation water. Total consumptive use of applied irrigation water was calculated by B&E as the "average annual" crop unit value and was identical for each year of their 5-year period. Gross applied irrigation demand was apparently adjusted by a 35 percent return flow factor to arrive at "net" consumptive use for their 5-year 1961 to 1965 base period of about 698,000 afy.

Table 42. Percolation of Irrigation Return Water
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	8,172	30,741	19,295	49,558	53,271	56,657	**217,694**
1982	7,552	28,077	17,920	46,054	50,010	53,215	**202,828**
1983	7,155	24,766	16,219	42,049	43,138	43,927	**177,254**
1984	9,661	35,186	22,205	57,642	61,559	62,524	**248,777**
1985	8,791	30,684	19,687	52,025	55,972	57,505	**224,664**
1986	6,889	23,836	15,781	41,465	44,237	45,458	**177,666**
1987	7,880	26,197	17,119	45,806	48,738	49,256	**194,996**
1988	8,020	27,148	17,312	46,785	49,790	49,854	**198,909**
1989	7,981	26,668	17,083	46,418	49,576	50,394	**198,120**
1990	8,539	26,774	17,570	48,179	50,887	50,553	**202,502**
1991	7,613	23,629	15,322	42,299	43,955	43,513	**176,331**
1992	7,165	22,395	14,538	40,329	42,055	41,621	**168,103**
1993	7,089	21,375	14,194	39,449	39,764	39,107	**160,978**
1994	7,185	22,584	14,376	40,819	41,919	41,636	**168,519**
1995	6,575	19,583	12,729	36,008	36,508	36,495	**147,898**
1996	6,951	19,286	12,123	35,335	35,929	36,556	**146,180**
1997	7,265	20,480	12,329	36,167	36,410	37,130	**149,781**
1998	5,296	14,475	8,974	26,217	26,082	26,149	**107,193**
1999	7,007	19,240	11,359	33,695	32,988	34,605	**138,894**
Maximum	**9,661**	**35,186**	**22,205**	**57,642**	**61,559**	**62,524**	**248,777**
Minimum	**5,296**	**14,475**	**8,974**	**26,217**	**26,082**	**26,149**	**107,193**
Average	**7,515**	**24,375**	**15,586**	**42,437**	**44,357**	**45,061**	**179,331**

6.2.2.6 Percolation of Wastewater

The cities of Visalia, Tulare and Farmersville operate wastewater treatment plants (WWTP) in the District that discharge treated wastewater to holding ponds for percolation, evaporation, or agricultural reuse. All three WWTPs are regulated by Waste Discharge Requirements (WDRs) and Monitoring and Reporting Programs (MRP) by the California State Regional Water Quality Control Board. Other regulated discharges also occur in the District (notably dairy farm discharges) but the overall contribution, as a component of inflow to the groundwater system is viewed as small and is not considered further (Collar, 2002).

Individuals knowledgeable about daily wastewater discharge volumes and reuse at all three facilities were interviewed to assess annual recharge (inflow) volumes from these sources. The Visalia WWTP has reported daily discharge of wastewater ranging from about 9.3 million gallons per day (mgd) in 1990 to approximately 12.1 mgd in 2000. Discharge reportedly is contained in several onsite storage percolation basins (about 80 acres in total size) and then used for irrigation of about 900 acres of walnut orchards. Any excess water not stored or used for irrigation is routed to Mill Creek. Discharge data prior to 1990 are not readily available but presumably follow the pattern of population growth and have been extrapolated from the annual data from 1990 to 2000. Wastewater discharged ranged from about 7,900 afy in 1981 (extrapolated) to 12,500 afy in 1999. All discharges from the Visalia WWTP occur in Hydrologic Unit No. III. Of the amount discharged, it is apparent that applied irrigation water for the walnut orchards can consume no more than about 3,000 afy (consumptive use of 3.0 af per acre per year). As such, a factor of 60 percent of the reported annual discharges were assumed to return to the groundwater reservoir as a component of inflow. Table 43 - Summary of Wastewater Return Flows, provides a tabulation of the annual volumes for the Visalia WWTP.

The City of Tulare discharges wastewater to percolation and storage ponds for agricultural reuse on about 1,500 acres of cotton and silage. The disposition of wastewater from the City of Farmersville WWTP is similarly assumed to be percolation ponds and for reuse in proximate irrigated agriculture.

6.2.3 Components of Outflow

6.2.3.1 Subsurface Outflow

Estimates of the annual quantities of subsurface outflow from the District and from each hydrologic unit were made in the same manner as the estimates of inflow and derived from the analysis contained in Chapter 3. Results of the analyses are summarized on Table 44 - Summary of Subsurface Groundwater Outflow Calculations.

Annual totals for each year of the base period are provided by each hydrologic unit as well as total District outflow volumes, the latter being about 24,900 afy. As indicated, annual subsurface outflows ranged from about 8,800 afy (1987) to about 50,700 afy (1997). As stated previously, there was a "net" average annual gain of subsurface inflow into the District of about 30,700 afy over the base period.

Table 43. Summary of Wastewater Return Flows
(in acre-feet per year)

Calendar Year	City of Visalia	City of Tulare	City of Farmersville	Total
	Hydrologic Unit No. III	Hydrologic Unit No. V	Hydrologic Unit No. IV	
1981	4,728	2,951	600	8,278
1982	4,917	3,051	498	8,466
1983	5,107	3,151	508	8,766
1984	5,296	3,251	517	9,065
1985	5,486	3,352	540	9,377
1986	5,676	3,452	449	9,576
1987	5,865	3,552	570	9,987
1988	6,055	3,652	515	10,222
1989	6,245	3,752	558	10,555
1990	6,299	3,853	457	10,608
1991	6,438	3,977	463	10,878
1992	6,329	3,689	467	10,485
1993	6,556	4,077	473	11,106
1994	6,865	4,481	482	11,829
1995	7,011	4,639	512	12,162
1996	6,966	4,638	503	12,106
1997	7,251	4,682	538	12,471
1998	7,446	4,726	464	12,636
1999	7,671	5,171	533	13,375
Maximum	7,671	5,171	600	13,375
Minimum	4,728	2,951	449	8,278
Average	6,221	3,900	508	10,629

Table 44. Summary of Subsurface Groundwater Outflow Calculations
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	District Inflow	District Outflow	District Net
1981	17,711	9,964	1,646	68,426	16,277	0	73,596	46,214	27,382
1982	27,793	18,010	9,344	52,246	14,616	0	64,523	32,159	32,364
1983	14,810	12,333	4,548	73,225	33,867	0	61,820	48,858	12,962
1984	15,294	20,551	5,177	56,513	35,298	0	86,961	38,720	48,241
1985	11,054	8,177	2,367	33,185	26,713	70	47,110	16,120	30,990
1986	27,130	18,583	711	29,026	31,336	835	45,126	24,753	20,373
1987	25,027	6,965	2,445	20,381	24,406	0	54,288	8,776	45,512
1988	15,413	9,777	8,276	26,461	5,126	0	35,884	12,509	23,375
1989	23,275	8,909	4,982	25,920	6,678	965	36,796	23,012	13,784
1990	18,745	7,490	9,245	22,787	7,849	0	53,527	11,891	41,636
1991	28,841	6,121	7,940	26,923	6,494	435	59,906	18,111	41,795
1992	35,144	2,039	15,507	16,996	2,603	0	62,895	9,334	53,561
1993	32,717	9,609	8,217	26,468	10,217	300	48,130	13,806	34,324
1994	29,238	1,121	10,228	26,018	17,929	3,297	36,643	13,321	23,322
1995	30,611	1,785	12,028	29,797	9,263	16	59,813	12,445	47,368
1996	13,490	12,761	8,550	50,202	9,570	544	71,533	35,147	36,386
1997	28,794	17,466	6,109	70,966	8,547	0	68,574	50,716	17,858
1998	23,528	8,694	4,977	44,180	23,432	7,042	49,156	24,890	24,266
1999	14,920	7,278	5,545	47,676	17,386	11,874	39,534	32,363	7,171
Maximum	35,144	20,551	15,507	73,225	35,298	11,87 4	86,961	50,716	53,561
Minimum	11,054	1,121	711	16,996	2,603	0	35,884	8,776	7,171
Average	22,818	9,875	6,729	39,337	16,190	1,336	55,569	24,902	30,667

6.2.3.2 Groundwater Pumpage

6.2.3.2.1 Agricultural Water Demand and Consumptive Use

Basic Methodology. Equations [1], [2], and [3] were used to develop estimates for both applied and consumptively used agricultural water in the District. The required annual water application for irrigated crops, at the farm gate, can be estimated using equation [1]. For the purposes of this study, on-farm conveyance losses, which can be significant due to the prevalent use of unlined ditches in the area, are considered part of the irrigation efficiency term.

$$AF/yr = \sum (Ac \bullet (ET_{cyr} - PPT_{eff}) / ((1 - LR) \bullet IE)) \qquad [1]$$

Where:

- $\sum$ = The summation of all crops for the year
- AF/yr = required annual delivery at the farm gate in af
- Ac = crop acreage
- ET_{cyr} = annual net crop water use in af/acre (evapotranspiration)
- PPT_{eff} = annual effective rainfall (rainfall that infiltrates and is stored for subsequent use by the crop) in af/acre
- LR = required leaching ratio to maintain a salt balance as a decimal
- IE = irrigation efficiency, which includes on-farm conveyance losses, as a decimal

Also, for any one crop:

$$ET_{cyr} = \sum Kc \bullet ET_r \qquad [2]$$

Where:

- $\sum$ = implies a summation throughout the year
- ET_{cyr} =annual net crop water use in af/acre
- Kc = crop coefficient relating crop water use to a reference water use
- ET_r = reference water use (evapotranspiration)

Also, for any given cropping situation:

$$LR = ECi / ((5 \bullet ECe) - ECi) \qquad [3]$$

Where:

- LR = required leaching ratio to maintain a salt balance as a decimal
- ECi = electrical conductivity of the irrigation water (a measure of salinity in deciSiemens/meter)
- ECe = electrical conductivity of the saturated soil extract (a measure of the salinity of the soil water solution in the rootzone of the crop in deciSiemens/meter)

When using equation [3] to determine LR, ECi is normally assumed to be known and ECe is set equal to a value sufficient to prevent yield declines.

To assist the reader, Figure 5 is a cross section of the field, showing the "destinations" of applied irrigation water expressed in afy.

- **Immediate evaporation** - part of irrigation inefficiency - a non-beneficial use.
- **Immediate surface runoff -** part of irrigation inefficiency - a non-beneficial use.
- Water is stored in the rootzone for crop water use **- ETc,** a beneficial use.
- Enough water is applied in addition to ETc to create the **Leaching Fraction** required to maintain a salt balance. This water theoretically would go to the water table but is considered a beneficial use for purposes of determining required afy.
- **Irrigation inefficiencies due to too much time** of application will create deep percolation.
- **Irrigation inefficiencies due to non-uniformity** of application will create deep percolation and it is important to note that this is non-uniform with time. Thus, there is likely to be more or less deep percolation in any one part of the field from irrigation to irrigation.

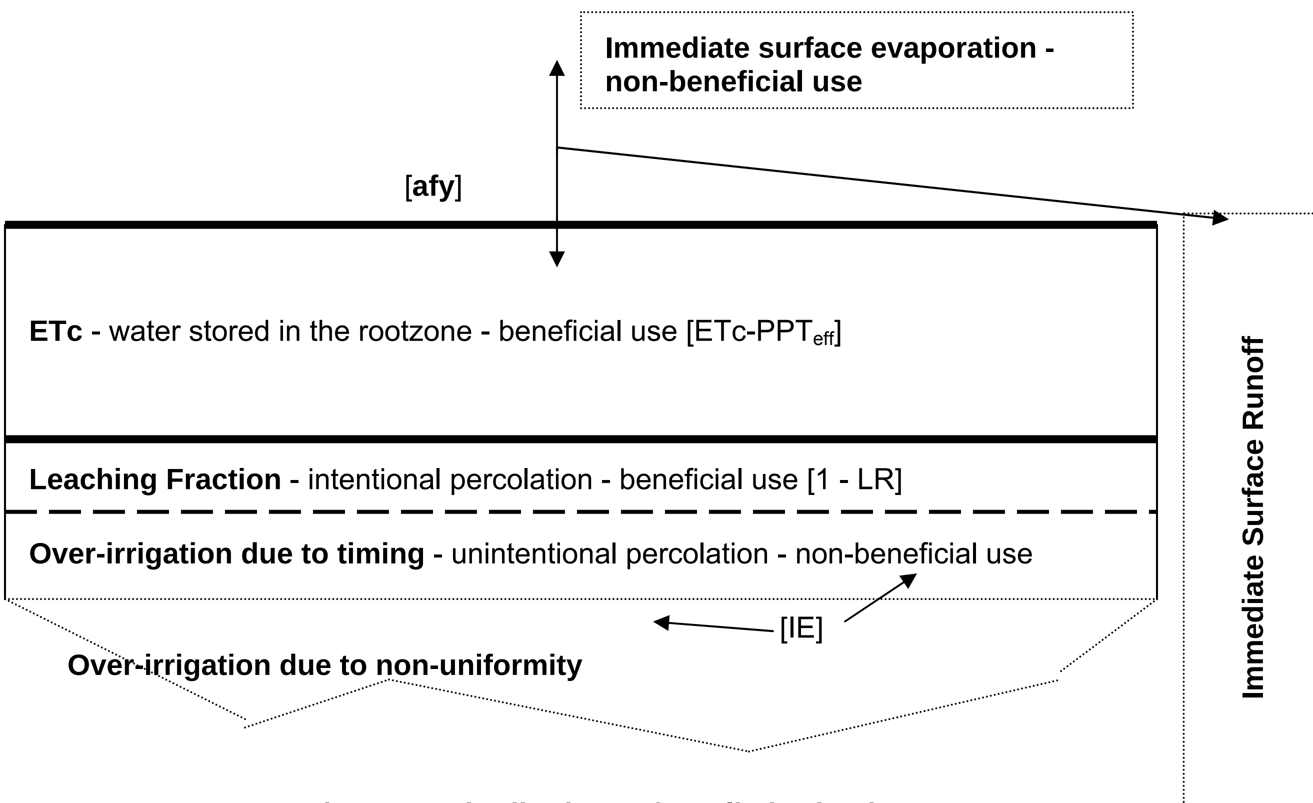

Figure 5. Distributions of Applied Irrigation Water

For the District study, IE considers inefficiencies due to both in-field and on-farm conveyance system losses. As an example, if 3.2 inches are needed on the field as beneficial use (for ETc and leaching purposes), and the assumed IE is 80 percent, 4.0 inches needs to be delivered to the farm gate to get 3.2 inches on the field. For this study, the 80 percent IE considers both farm conveyance and irrigation system losses.

Further, of the 3.2 inches that is considered beneficial use, theoretically a portion of that is a leaching fraction (calculated using the required leaching ratio LR). This fraction is intentional deep percolation. It does return to the groundwater system and is available for re-use. However, it is separate from the deep percolation due to the irrigation inefficiencies.

A series of equations are also used to determine effective rainfall PPT_{eff} as a result of gross rainfall. These equations account for the amount of rain per event, whether or not a crop is present, and the rate of crop water use at the time of rain. As a result of these calculations, some of the gross rainfall becomes deep percolation and is a component of recharge to the aquifer.

The irrigation water in the District is very high quality. Thus, the deep percolation from rainfall, in addition to non-uniform deep percolation from irrigation inefficiencies, is assumed to supply any required leaching fraction.

Thus, for this study, equation [1] is modified to equation [1a]:

$$AF/yr = Ac \times (ET_{cyr} - PPT_{eff}) / IE \qquad [1a]$$

Applied Water Versus Consumptive Use. An important factor in the development of the hydrologic balance is an understanding of consumptive use of water versus required pumping for irrigation water applications. Consumptive use (water lost to the hydrologic system) is usually different than the required irrigation application. Estimating actual consumptive use involves an identification of the types of irrigation inefficiencies and the destinations of the losses due to irrigation inefficiencies. That is, does the water delivered and applied in excess of crop water needs return to a usable body of water within or outside the basin, or does it return to an unusable water body such as a saline lake? Of importance is that irrigation application "losses" on one farm may be used on another farm, or on the same farm on a different field, or on the same field at a later time. Examples of these situations are when deep percolation returns to a groundwater basin for later re-pumping or when surface runoff is intercepted for storage or for immediate re-use.

After physical inspection of the District and interviews with knowledgeable personnel, it is considered appropriate to assume that there is little surface water flowing out of the District as a whole, except in extremely high rainfall and surface water runoff years (e.g., 1995, TID Spill). Any water delivered to a farm in the District is also assumed to not leave that farm in the form of surface flows. This implies that surface flows from irrigation runoff from one hydrological unit to another hydrologic unit does not occur or is not significant. Rainfall runoff from agricultural fields is further assumed to be captured in the on-farm irrigation systems for infiltration or evaporation, except for years of very high rainfall. Thus, absent accurate data to the contrary, it is assumed that all rainfall falling on agricultural land in any one hydrologic unit stays within that hydrologic unit.

Based on the above assumption, the important conclusions are that percolation of water below the rootzone from excessive irrigations or infiltrated rainfall returns to the groundwater for subsequent re-pumping. Surface runoff from rainfall is captured in on-farm ditches and reservoir system for re-use, typically in the off-season and becomes percolation (recharge) to the groundwater system. Surface runoff from any excessive irrigation is assumed to be captured in the on-farm ditch and reservoir systems for subsequent re-use.

Thus, consumptive use of water on irrigated land in the District includes only crop evapotranspiration, immediate evaporation from the soil surface during or just after irrigation rainfall, or frost control events, immediate evaporation from the soil surface due to flush water from micro-irrigation filters, evaporation from water surfaces in reservoirs, and evaporation of standing rainwater. The calculations for equation [1] were done on an October through September (traditional water year) basis. This allowed for a more accurate accounting of off-season rainfall stored in the rootzone for seasonal water use as well as matching up with the standard water year of the Federal Bureau of Reclamation and the California Department of Water Resources.

Acreages of the different crops grown in the District were aggregated by eleven standard land use groups in accordance with the B&E report (1972), within each of the six hydrologic units, for each year in the base period. The major groupings used included:

- Cotton
- Alfalfa
- Grain
- Deciduous nuts and fruits
- Pasture
- Miscellaneous field crops
- Sugarbeets
- Vineyards
- Citrus
- Rice
- Truck crops

Truck crops land use in the District was described in the B&E report (1972) based on information available for the U.S. Bureau of Reclamation, the State DWR, and the District. Land use data from 1958 and 1968 surveys of both Tulare and Kings Counties were compiled into several tables according to the principal crop types. Importantly, the District survey of 1968 allowed determination of crop types and acreage for each of the hydrologic units, which facilitated the water balance performed by B&E at the time. A general comparison of land use over the last 50 years (in approximate 10-year-measurements) is provided in Table 45 - Comparison of Land Use Data. As Table 45 indicates, the acreage of irrigated lands and urbanized areas have increased during the period.

Table 45. Comparison of Land Use Data
(in acres)

Land Use Category	1958 (1)	1968 (2)	1981	1991	1996
Irrigated	224,800	255,900 (3)	263,255	266,313	278,555
Idle or Fallow (including roads and canals)	39,100	27,900 (3)	15,968	10,470	8,895
Urban	7,500	10,700	21,352	30,735	29,815
Farmsteads	3,500	4,500	10,397	10,129	12,008
Undeveloped	61,800	37,700	28,833	22,404	9,723
Totals:	336,700	336,700	341,786 (4)	342,042 (4)	340,992 (4)

(1) By USBR and DWR
(2) By KDWCD
(3) Gross area; net cropped area is 245,680 acres.
(4) Total area based on GIS output does not equal calculated total. Difference is within 0.5%.

For the present study, land use data for Tulare and Kings counties were available in digital form from 1991 and 1996.

Such digital land use data could be easily tabulated for any given area of the District using ARCVIEW. For the early 1980s, land use data were available from the State DWR only in the typical field sheets, standard USGS 7-1/2 minutes Series topographic maps. Such land use data had not been formally digitized by the DWR, although Tulare County land use for 1985 had been digitized by staff at the University of California, Davis, as part of a research project. Such digitized land use data were graciously provided to Fugro for use. The remaining Kings County land use data from 1982 were obtained from the DWR in standard USGS 7-1/2 minute maps (approximately 20 sheets) and the remaining portion of the District within Kings County digitized. Major land uses from the three periods (1981, 1991, and 1996) were compiled. Land use acreages for each intermediate year were calculated by straight-line interpolation based on the years with survey data. Summaries of the land use data are provided in Appendix E in both tabular and graphical form. A graphical depiction of changes in acreage for the major land use types and major crops are shown in Appendix E. Irrigated lands in the District have increased from about 256,000 acres in 1968 to approximately 280,000 in 1999. Similarly, urban land use has increased from about 11,000 to 30,000 acres over the same time period. Fallow, idle lands, or lands previously considered unproductive or marginal agricultural lands, as well as undeveloped land, have accommodated the increased irrigated agricultural and urban development.

Reference Evapotranspiration (ET_r). The CIMIS is a statewide network of standardized, calibrated weather stations developed by the University of California at Davis and now maintained by the California Department of Water Resources. The main function of the stations in this system is to calculate an estimate of ET_o. ET_o is a reference evapotranspiration equivalent to the evapotranspiration of a lush, well-watered pasture. ET_o, in conjunction with suitable crop coefficients, is commonly used in place of ET_r in equation [2] above.

DWR has recently developed a statewide ET_o map. Dr. Rick Snyder of the University of California at Davis (an author of the map) has indicated that much statistical analysis was performed to ensure that the areas delineated are sufficiently accurate for long-range water-use studies. Much of the District lies within ET_o Zone 12, with a substantial portion of Hydrologic Unit No. VI lying within ET_o Zone 16.

CIMIS has maintained a station in the District just south of Visalia continuously since 1983 (station number 33). Thus, daily estimates of ET_o are available from January 1983 through December 1999 for ET_o Zone 12. These data were used for Hydrologic Unit Nos. I through V. CIMIS has also maintained a station at Stratford (station number 15) since November 1982. These data were used for Hydrologic Unit No. VI.

In addition, the U.S. Weather Service has maintained a weather station in Visalia since 1933. Although this station does not record data required for an estimate of ET_o, temperature data from this station were used to synthesize actual monthly ET_o for 1980, 1981, and 1982 for all hydrologic units. To accomplish this the average for each months' average of the daily maximum and daily minimum temperatures for 1980 through 2000 was computed for the Visalia Weather Bureau station. The monthly average ET_o for 1983 through 2000 was then calculated for CIMIS stations 33 and 15. For 1980, 1981, and 1982, each month's actual average of daily maximum and minimum temperatures at the USWB station was divided by the long term average and then multiplied by the average monthly ET_o at CIMIS station 33 or station 15. For example:

$$ET_o\_Jan81 = ET_o\_JanAvg \bullet TMxMn\_Jan81 / TMxMn\_JanAvg$$

Where:

ET_o_Jan81	=	estimated actual ET_o for January 1981 at CIMIS station 33
ET_o_JanAvg	=	average ET_o for January from 1983 through 2000 at CIMIS station 33
TMxMn_Jan81	=	average of daily maximum and minimum temperatures for January 1981 at the Visalia USWB station
TMxMn_JanAvg	=	average of daily maximum and minimum temperatures for January from 1980 through 2000 at the Visalia USWB station

Crop Coefficients (Kc). Crop coefficients were estimated using the convention adopted by the University of California. This convention assumes that the crop coefficient curve (the relationship between crop coefficients and date) for an annual crop is in the form of Figure 6. Here, the A date is planting, the B date is the onset of what is termed "rapid growth", the C date is maximum evapotranspiration rate, D is the onset of senescence, and E is harvest. The convention is modified somewhat for a perennial crop as in Figure 7. Here, date B is "leaf out," the C date is maximum evapotranspiration, D is the onset of senescence, and E is total leaf drop.

The main source of data to define these curves for this study was Publication 21454, "Irrigation Scheduling" (Pub 21454) published by the University of California. This publication contains estimates of crop coefficient curves for many crops grown in California. Table 46 - Crops Used to Develop Crop Coefficient Curves for the Eleven Crop Groups, lists the crop data from Pub 21454 used for this study and which were average for each of the eleven crop groups noted above.

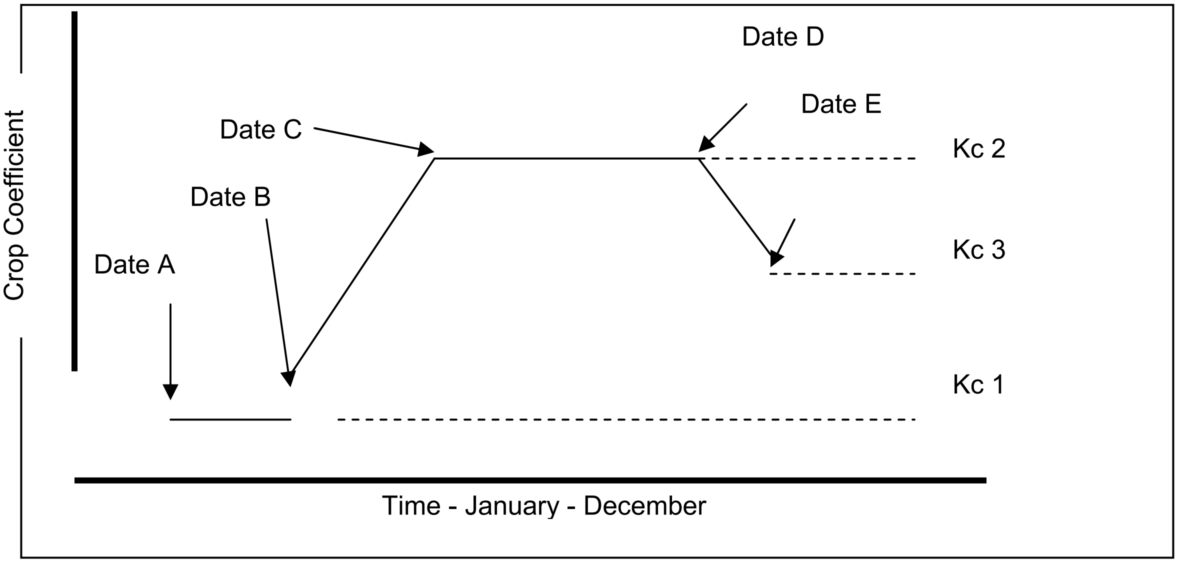

Figure 6. Schematic Depicting a Crop Coefficient Curve for an Annual Crop

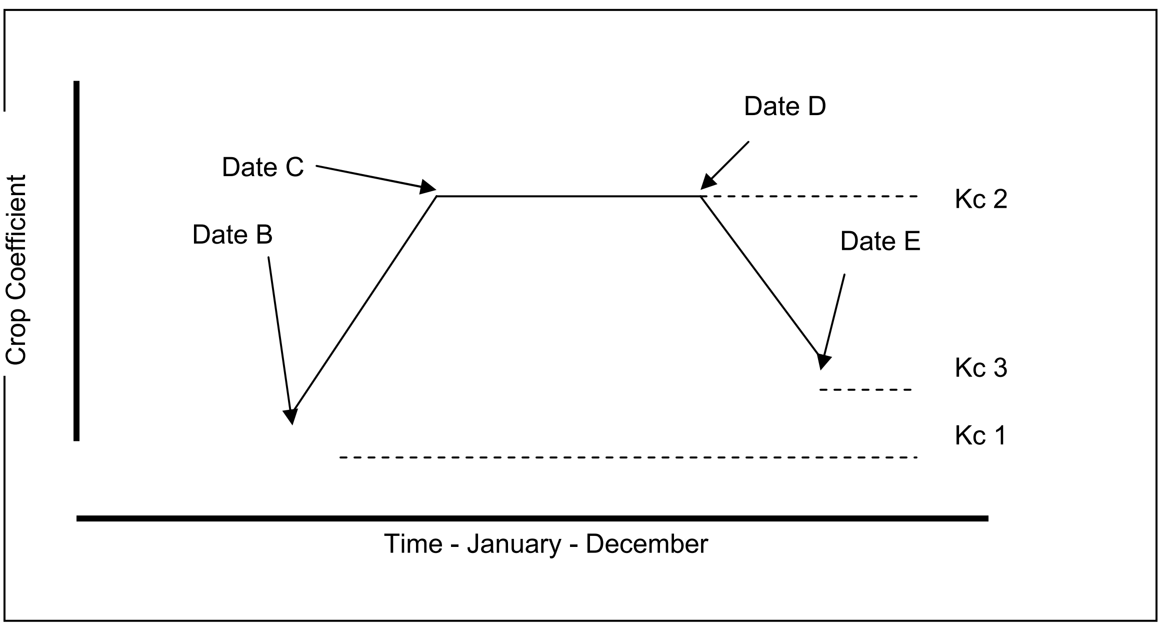

Figure 7. Schematic Depicting a Crop Coefficient Curve for a Perennial Crop

Table 46. Crops Used to Develop Crop Coefficient Curves for the Eleven Crop Groups

DWR Crop Group	Crop Name	Date A	Date B	Date C	Date D	Date E	Kc 1	Kc 2	Kc 3
1	Cotton	4/16	5/18	7/6	8/19	10/15	0.16	1.18	0.40
2	Alfalfa	2/15	10/15	1/0	1/0	1/0	0.00	0.00	1.00
3	Small Grains	11/1	12/14	1/25	3/25	5/15	0.25	1.20	0.40
4	Deciduous Orchard - with Cover Crop	2/15	2/15	6/1	9/4	11/10	0.85	1.20	0.75
4	Deciduous Orchard - without Cover Crop	2/15	2/15	6/1	9/4	11/10	0.50	0.90	0.50
4	Deciduous-Walnuts	3/15	3/15	7/7	9/2	11/15	0.45	1.14	0.15
4	Deciduous-Olive	1/1	1/1	9/4	12/27	12/31	0.80	0.80	0.80
5	Pasture	1/1	1/1	9/4	12/27	12/31	0.90	0.90	0.90
6	Melons	3/16	4/17	5/23	6/26	7/31	0.18	1.11	0.08
6	Potato-late	3/1	3/21	4/26	5/23	6/30	0.55	1.21	0.30
6	Tomato-Canning	3/15	5/9	6/20	7/10	8/25	0.24	1.12	0.70
6	Beans	4/1	4/30	5/25	6/29	7/31	0.14	1.15	0.30
6	Onion	3/1	4/11	5/24	6/24	8/31	0.30	1.14	0.63
6	Corn	4/1	4/25	6/14	7/13	8/31	0.19	1.17	0.40
7	Sugar Beets	3/1	4/27	6/13	8/8	10/1	0.24	1.13	0.90
8	Grapes	3/15	3/15	6/15	8/4	10/5	0.27	0.82	0.34
9	Citrus	1/1	1/1	9/4	12/27	12/31	0.65	0.65	0.65
10	Rice	4/1	4/26	5/28	6/29	8/31	0.95	1.25	0.95
11	Miscellaneous Truck	3/1	4/1	5/1	5/24	6/30	0.30	0.95	0.50

Computer programming was used to develop average monthly crop coefficients for each of the crops listed in Table 46. These were compared to bi-weekly crop coefficients as listed by Hanson, et al. In addition, the developed monthly crop coefficients were multiplied by the long-term average monthly ET_o values from CIMIS 33 and compared to similar estimates of annual ETc developed by Naugle (2001) in an earlier study of the Tule basin. Although not a perfect match in each instance (the reader is cautioned that many methods are in use to estimate crop water use), the results were felt to be reasonable. The final monthly crop coefficients for each of the crops and the crop groups are listed in Table 47 - Monthly Crop Coefficients and Annual Crop Evapotranspiration in Zones 12 and 16 for the Eleven Crop Groups. Also in Table 47 are calculations of the average annual crop water use in both ET_o Zone 12 and Zone 16.

Table 47. Monthly Crop Coefficients and Annual Crop Evapotranspiration in Zones 12 and 16 for the Eleven Crop Groups

Crop Group	Group Name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual Inches ETc Zone 12	Annual Inches ETc Zone 16
1	Cotton	0.00	0.00	0.00	0.08	0.22	0.75	1.17	1.15	0.81	0.23	0.00	0.00	29.81	34.07
2	Alfalfa	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	46.53	53.81
3	Small Grains	0.98	1.20	1.19	0.87	0.23	0.00	0.00	0.00	0.00	0.00	0.25	0.36	14.27	16.44
4	Deciduous Nuts/Fruits	0.20	0.37	0.66	0.80	0.90	0.98	1.01	1.01	0.93	0.73	0.33	0.19	44.03	50.80
5	Pasture	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.87	46.96	54.22
6	Miscellaneous Field Crops	0.00	0.00	0.18	0.38	0.80	1.02	0.72	0.33	0.00	0.00	0.00	0.00	24.07	27.47
7	Sugar Beets	0.00	0.00	0.24	0.24	0.60	1.08	1.13	1.09	0.97	0.00	0.00	0.00	36.00	41.15
8	Grapes	0.00	0.00	0.17	0.46	0.64	0.80	0.82	0.73	0.49	0.05	0.00	0.00	27.79	31.82
9	Citrus	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.63	33.91	39.16
10	Rice	0.00	0.00	0.00	0.95	1.14	1.25	1.17	0.99	0.00	0.00	0.00	0.00	38.65	44.13
11	Truck Crops	0.00	0.00	0.30	0.61	0.94	0.66	0.00	0.00	0.00	0.00	0.00	0.00	15.91	18.33

There were several modifications to the crop coefficients for immature plantings of citrus, grapes, and deciduous fruits and nuts. It was assumed that 5 percent of the acreage of each of these crop groups was replanted each year. Also, since annual acreages were estimated, the development of new acreage was tracked to identify various stages of growth for these groups. Five stages of development were used for each. Table 48 - Assumed Percentage of Normal Crop Water Use for Various Stages of Citrus, Vineyard, or Deciduous Nuts/Fruits Orchard Development, lists the stages and the assumed percentage of full ETc used for the calculations.

Table 48. Assumed Percentage of Normal Crop Water Use for Various Stages of Citrus, Vineyard, or Deciduous Nuts/Fruits Orchard Development

Stage of Citrus, Vineyard, or Orchard Development	1st Year	2nd Year	3rd Year	4th Year	Mature
Assumed % of Normal ETc	20%	40%	60%	80%	100%

Effective Rainfall (PPT_{EFF}). With regard to effective rainfall, the following excerpt from Hanson, et al. (1999) is repeated here:

> "Effective rainfall is that part of total rainfall satisfying the crop evapotranspiration requirements or stored in soil. Effective rainfall depends on amount of total rainfall, soil moisture depletion at the time of the rainfall, frequency of occurrence of rainfall, timing of rainfall with respect to the growing season, and absence or presence of growing crops.

"Estimating effective rainfall can be difficult. High-intensity rainfall may result in much surface runoff resulting in little effectiveness. Small amounts of rainfall on dry soil with little vegetation may be lost to evaporation.

"Guidelines on effective rainfall have been established by the Natural Resources Conservation Service (USDA), formerly the Soil Conservation Service. These guidelines, provide a method for calculating effective rainfall if monthly mean rainfall and average monthly crop evapotranspiration are known. This procedure is appropriate for use during the growing season.

"Most areas in California experience substantial rainfall only during the winter and early spring. Rainfall during the growing season usually is negligible. Thus, effective rainfall in these areas is the amount stored in soil during periods of rainfall minus evaporation and drainage from the soil below the root zone between time of the rainfall and start of the crop-growing season.

"Much uncertainty exists in estimating effective rainfall under these conditions. The California Department of Water Resources studied effective rainfall at 10 locations in the San Joaquin Valley between 1983 and 1987. A variety of relationships between cumulative rainfall and cumulative changes in soil moisture content were found.

"Based on this study, the average effective rainfall was found to be about 50 percent of total rainfall during the winter months. However, the range of values was 16 to 79 percent reflecting time and site-specific nature of effective rainfall. The best method to determine stored soil moisture from rainfall in the soil profile is to measure soil moisture contents at the start of the growing season."

From the above quote, it should be recognized that estimates of effective rainfall can be difficult. Estimating effective rainfall for this project was performed in the following manner. Since crop acreages were available for each hydrologic unit, zones of equal rainfall were developed for each unit. This was performed by creating monthly isoheytal maps for the District using a contour program (SURFER) and then averaging the monthly rainfall for each hydrologic unit using GIS. Precipitation information was from the stations in or immediately surrounding the District, as discussed in Chapter 1, and the same stations were used to develop the study base period. Effective rainfall was then estimated separately for in-season and off-season periods for each of the crop groups. For the off-season period, a certain percentage of monthly gross rainfall was assumed to infiltrate the cropped soil. This infiltrated rainfall would be assumed effective, up to a maximum value. This maximum value was assumed to be 60 percent of the available water holding capacity of a 4-foot effective rootzone (that depth of soil where the crop is going to extract most water for evapotranspiration). Sixty percent dryness was assumed so as to model the status of the effective root zone at the end of the previous season.

Two very old soil surveys were available for the study area. These reports each contained maps of soil distribution and estimates of field capacity for the soils in the District. An examination of the General Soil Map for each of these surveys indicated a wide range of soils used for agriculture in the District. Table 39 presented in Chapter 6 lists the major soil types in each hydrologic unit and the assumed average field capacity. The assumed available water holding capacity is 70 percent of the assumed field capacity. The available storage for off-season rainfall is assumed to be 60 percent of the available storage capacity over a 4-foot rootzone.

Effective rainfall in-season was estimated using the relationships listed in Table 49 - Average Monthly Effective Rainfall In Inches as Related to Monthly Gross Rainfall and Monthly Crop Evapotranspiration (ETc), between gross rainfall, crop water use, and resulting effective rainfall. The information in Table 49 is taken from NEH-2 (1993). As an example of using Table 49, if the gross monthly rainfall was 2.5 inches and the monthly crop ETc was 3.0 inches, then the estimated effective rainfall would be 1.65 inches.

Table 49. Average Monthly Effective Rainfall In Inches as Related to Monthly Gross Rainfall and Monthly Crop Evapotranspiration (ETc)

Monthly ETc (inches)	Gross Monthly Rainfall (inches)																
	0	.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
0.0	0.00	0.28	0.59	0.87	1.14	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39
1.0	0.00	0.30	0.63	0.93	1.21	1.47	1.73	1.98	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23	2.23
2.0	0.00	0.32	0.66	0.98	1.27	1.56	1.83	2.10	2.36	2.61	2.86	3.10	3.10	3.10	3.10	3.10	3.10
3.0	0.00	0.34	0.70	1.03	1.35	1.65	1.94	2.22	2.49	2.76	3.02	3.28	3.53	3.79	4.03	4.03	4.03
4.0	0.00	0.36	0.74	1.09	1.43	1.74	2.05	2.35	2.63	2.92	3.20	3.47	3.74	4.00	4.26	4.52	4.78
5.0	0.00	0.38	0.78	1.16	1.51	1.84	2.17	2.48	2.79	3.00	3.38	3.67	3.95	4.23	4.51	4.78	5.05
6.0	0.00	0.40	0.83	1.22	1.59	1.95	2.29	2.62	2.95	3.26	3.57	3.88	4.18	4.48	4.77	5.06	5.34
7.0	0.00	0.42	0.88	1.29	1.69	2.06	2.42	2.77	3.12	3.45	3.78	4.10	4.42	4.73	5.04	5.35	5.65
8.0	0.00	0.45	0.93	1.37	1.78	2.18	2.56	2.93	3.29	3.65	4.00	4.34	4.67	5.00	5.33	5.65	5.97
9.0	0.00	0.47	0.98	1.45	1.88	2.30	2.71	3.10	3.48	3.86	4.23	4.50	4.94	5.29	5.64	5.98	6.32
10.0	0.00	0.50	1.00	1.50	1.99	2.44	2.86	3.28	3.68	4.08	4.47	4.85	5.23	5.60	5.96	6.32	6.68

Leaching Ratios (LR). As noted in the explanation for equation [3], normally an ECe is chosen so as to ensure full crop yields. This is generally termed the threshold ECe. Table 50 - Assumed Threshold Rootzone Salinity (ECe) and Required Leaching Ratio for Irrigation Water Quality, lists the assumed threshold ECe values for the different crop groups. These numbers were developed using data from tables contained in NEH-2 (1993) of ECe for various crops. Table 50 lists the required leaching ratio calculated using equation [3] and an assumed irrigation water quality of 0.07 dS/m.

Table 50. Assumed Threshold Rootzone Salinity (ECe) and Required Leaching Ratio for Irrigation Water Quality

Crop Group	Group Name	Threshold Rootzone Salinity - ECe (deciSiemens/M)	Required Leaching Ratio with Irrigation Water Quality = 0.07 dS/M (Percent)
1	Cotton	7.7	0.18
2	Alfalfa	2.0	0.71
3	Small Grains	4.0	0.35
4	Deciduous Nuts/Fruits	1.7	0.83
5	Pasture	6.0	0.23
6	Miscellaneous Field Crops	1.7	0.83
7	Sugar Beets	2.9	0.49
8	Grapes	1.5	0.94
9	Citrus	2.5	0.56
10	Rice	3.0	0.47
11	Truck Crops	1.5	0.94

Due to the very low required leaching ratios indicated, this study assumes that all natural rainfall and excessive irrigations, will account for required leaching of all crop groups.

Irrigation Efficiency (IE). "Irrigation efficiency" is an ambiguous term that has both spatial and temporal implications. In terms of spatial boundaries, the question is whether the measurement is for a field, for a farm, for an irrigation district, or for a basin. It also depends on whether the measurement is for one irrigation, for a season, or for a hydrologic period. There are also a number of other direct factors including irrigation system design, system maintenance, and system management. For this study it is assumed that the measure of irrigation efficiency is the seasonal average for an individual field.

Another aspect of estimating IE is the particular time period involved, 1981 - 1999. This period encompasses one of the most significant droughts in the State's history and has been a period of generally increasing awareness of the need for improved water resources management. Thus, the models used to estimate both required pumping and consumptive use attempt to account for this.

Different irrigation efficiencies may be used for different crop types. This is sometimes due to the type of irrigation systems being used, but also is affected by the general economics of the cropping system. Table 51 - Assumed In-Field Irrigation Efficiencies for Different Crop Groups, lists the irrigation efficiencies assumed for the different crop groups for four different time periods. These estimates are based on known improvements in irrigation efficiency evaluation in the late 1980s and on published data.

Table 51. Assumed In-Field Irrigation Efficiencies for Different Crop Groups

Crop Group	Period			
	1980-1985 (Percent)	1986-1990 (Percent)	1991-1995 (Percent)	1996-1997 (Percent)
Cotton	70	74	78	78
Alfalfa	70	74	78	78
Grains	70	74	78	78
Deciduous Nuts and Fruits	70	72	75	77
Pasture	70	72	74	77
Miscellaneous Field Crops	70	72	74	77
Sugarbeets	70	72	74	77
Vineyards	70	72	74	77
Citrus	72	75	78	78
Rice	70	72	74	77
Truck Crops	70	72	74	77

Standard procedures were used for determining distribution uniformity of a system, which is the upper limit for irrigation efficiency.

Frost Control. According to conversations with University of California Cooperative Extension staff, water applications for frost control are considered negligible in the District and were not considered further.

Results of the Computations. Table 52 - Consumptive Use of Applied Irrigation Water, Entire District, tabulates the results of the computations using equation [1] and the data and methodology identified above. Applied irrigation water, or gross required irrigation water averaged about 809,100 afy in the District over the base period and ranged from about 574,900 af in 1998 to 997,000 af in 1984. Average annual unit crop demand data are also provided in Table 52 and indicate use of about 3.0 af per acre per year. Similar tables are provided for each of the six hydrologic units (Tables 53 to 58). As indicated, Hydrologic Units Nos. V and VI had applied irrigation water demands of almost 200,000 afy each, and relate to the size of the units and the intensive irrigated agriculture, which occur in this part of the District.

By comparison, for their 1961 to 1965 base period, B&E estimated the gross required irrigation demand on the District to be about 930,000 afy (irrigated acreage of about 256,000 acres). "Average" unit water use in the District at that time was about 3.6 af per acre per year. Changes in crop types and irrigation management practices in the District over the last 30 years have resulted in an apparent 17 percent decline in average unit water use.

Table 52. Consumptive Use of Applied Irrigation Water, Entire District

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	263,255	674,778	165,783	63,621	872,475	60,062	217,694	654,781	3.314
1982	263,564	647,879	223,612	78,475	812,877	76,521	202,828	610,049	3.084
1983	263,866	605,706	322,939	108,048	710,434	149,523	177,254	533,180	2.692
1984	264,173	720,316	73,722	21,933	997,011	22,277	248,777	748,234	3.774
1985	264,478	678,322	136,761	47,651	900,352	55,922	224,664	675,688	3.404
1986	264,788	644,957	246,328	86,627	774,735	113,083	177,666	597,069	2.926
1987	265,090	686,343	190,169	73,471	850,387	77,853	194,996	655,391	3.208
1988	265,398	670,493	149,732	45,273	867,503	46,848	198,909	668,594	3.269
1989	265,702	674,160	154,346	51,473	864,008	53,749	198,120	665,888	3.252
1990	266,007	692,662	176,201	56,106	883,217	63,841	202,502	680,715	3.320
1991	266,313	690,165	177,700	64,257	844,462	83,412	176,331	668,131	3.171
1992	268,762	655,471	147,608	58,798	805,027	58,616	168,103	636,924	2.995
1993	271,211	657,074	258,222	85,570	771,034	134,701	160,978	610,056	2.843
1994	273,659	647,896	177,626	49,675	807,094	61,043	168,519	638,575	2.949
1995	276,108	629,361	339,431	104,140	708,547	172,165	147,898	560,649	2.566
1996	278,557	680,690	239,577	83,725	782,259	102,905	146,180	636,079	2.808
1997	281,005	661,555	150,407	49,552	801,882	83,612	149,781	652,101	2.854
1998	283,454	573,918	491,329	134,959	574,898	275,012	107,193	467,705	2.028
1999	285,900	648,194	263,793	79,449	744,883	136,898	138,894	605,989	2.605
Maximum	285,900	720,316	491,329	134,959	997,011	275,012	248,777	748,234	3.774
Minimum	263,255	573,918	73,722	21,933	574,898	22,277	107,193	467,705	2.028
Average	270,068	659,997	215,015	70,674	809,110	96,213	179,331	629,779	3.003

Table 53. Consumptive Use of Applied Irrigation Water for Hydrologic Unit No. I

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	9,756	26,882	8,500	3,078	33,658	3,870	8,172	25,486	3.450
1982	9,836	26,117	12,292	4,117	31,107	5,302	7,552	23,555	3.163
1983	9,913	24,858	15,694	4,038	29,447	8,875	7,155	22,292	2.971
1984	9,991	29,710	5,495	1,594	39,764	2,505	9,661	30,103	3.980
1985	10,069	28,352	9,314	2,783	36,168	4,969	8,791	27,377	3.592
1986	10,149	27,213	14,378	4,331	31,339	8,095	6,889	24,450	3.088
1987	10,226	29,653	9,715	3,482	35,843	4,691	7,880	27,963	3.505
1988	10,305	29,262	7,299	2,584	36,524	2,338	8,020	28,504	3.544
1989	10,383	29,430	7,700	2,918	36,310	2,639	7,981	28,329	3.497
1990	10,463	30,889	9,329	2,531	38,839	4,246	8,539	30,300	3.712
1991	10,540	31,309	8,783	2,004	38,861	5,502	7,613	31,248	3.687
1992	10,992	30,199	7,511	2,639	36,552	3,604	7,165	29,387	3.325
1993	11,445	30,331	13,634	3,102	36,124	8,222	7,089	29,035	3.156
1994	11,893	30,348	9,912	2,762	36,601	4,118	7,185	29,416	3.078
1995	12,346	29,994	21,192	4,802	33,439	13,447	6,575	26,864	2.708
1996	12,797	33,407	13,863	3,708	38,579	7,592	6,951	31,628	3.015
1997	13,250	33,144	10,708	2,086	40,340	7,257	7,265	33,075	3.045
1998	13,698	29,462	31,962	6,794	29,436	21,072	5,296	24,140	2.149
1999	14,150	34,149	17,215	4,177	38,926	10,684	7,007	31,919	2.751
Maximum	14,150	34,149	31,962	6,794	40,340	21,072	9,661	33,075	3.980
Minimum	9,756	24,858	5,495	1,594	29,436	2,338	5,296	22,292	2.149
Average	11,169	29,722	12,342	3,344	35,677	6,791	7,515	28,162	3.232

Table 54. Consumptive Use of Applied Irrigation Water for Hydrologic Unit No. II

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	36,946	97,354	26,422	11,097	123,156	9,472	30,741	92,415	3.333
1982	37,083	93,001	37,083	14,213	112,491	12,347	28,077	84,414	3.033
1983	37,222	86,495	51,180	16,992	99,230	25,175	24,766	74,464	2.666
1984	37,359	102,057	10,896	3,317	140,975	2,780	35,186	105,789	3.774
1985	37,495	95,612	24,371	9,497	122,946	10,620	30,684	92,262	3.279
1986	37,634	90,345	43,277	15,438	103,940	20,915	23,836	80,104	2.762
1987	37,772	95,913	33,994	13,571	114,252	14,727	26,197	88,055	3.025
1988	37,909	93,188	23,691	7,846	118,410	7,419	27,148	91,262	3.124
1989	38,046	92,669	25,363	8,820	116,334	9,003	26,668	89,666	3.058
1990	38,184	94,103	29,060	9,890	116,828	10,467	26,774	90,054	3.060
1991	38,321	94,122	27,048	10,201	113,211	12,856	23,629	89,582	2.954
1992	38,727	88,895	21,946	9,331	107,325	8,147	22,395	84,930	2.771
1993	39,133	89,137	41,740	13,145	102,492	22,620	21,375	81,117	2.619
1994	39,537	88,416	27,676	8,099	108,317	9,802	22,584	85,733	2.740
1995	39,944	86,313	55,252	16,582	94,015	29,480	19,583	74,432	2.354
1996	40,346	94,542	41,355	15,406	103,603	17,867	19,286	84,317	2.568
1997	40,753	92,910	26,149	8,817	110,078	14,264	20,480	89,598	2.701
1998	41,156	81,069	80,940	21,428	78,017	46,371	14,475	63,542	1.896
1999	41,562	92,662	41,907	13,391	103,696	21,255	19,240	84,456	2.495
Maximum	41,562	102,057	80,940	21,428	140,975	46,371	35,186	105,789	3.774
Minimum	36,946	81,069	10,896	3,317	78,017	2,780	14,475	63,542	1.896
Average	38,691	92,042	35,229	11,952	109,964	16,084	24,375	85,589	2.853

Table 55. Consumptive Use of Applied Irrigation Water for Hydrologic Unit No. III

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	22,278	59,984	15,612	5,951	77,187	5,949	19,295	57,892	3.465
1982	22,175	57,442	20,510	7,259	71,687	7,143	17,920	53,767	3.233
1983	22,070	53,598	28,505	8,179	64,881	14,981	16,219	48,662	2.940
1984	21,967	63,500	5,125	1,315	88,833	1,150	22,205	66,628	4.044
1985	21,863	59,543	12,389	4,409	78,759	5,316	19,687	59,072	3.602
1986	21,761	56,312	22,848	6,900	68,624	11,945	15,781	52,843	3.154
1987	21,659	59,683	17,869	6,077	74,447	8,526	17,119	57,328	3.437
1988	21,554	57,979	12,573	3,765	75,291	4,017	17,312	57,979	3.493
1989	21,451	58,079	13,407	4,579	74,298	4,884	17,083	57,215	3.464
1990	21,345	59,525	14,407	4,504	76,410	5,564	17,570	58,840	3.580
1991	21,243	59,031	14,694	4,919	73,089	7,377	15,322	57,767	3.441
1992	21,217	55,953	11,846	4,606	69,354	4,792	14,538	54,816	3.269
1993	21,192	55,683	21,546	5,554	67,708	12,756	14,194	53,514	3.195
1994	21,166	54,484	13,758	3,709	68,580	4,993	14,376	54,204	3.240
1995	21,139	52,515	27,834	7,553	60,728	15,418	12,729	47,999	2.873
1996	21,111	56,294	20,057	6,368	65,315	9,460	12,123	53,192	3.094
1997	21,086	54,166	12,652	3,402	66,415	7,838	12,329	54,086	3.150
1998	21,060	46,545	39,310	9,508	48,433	23,078	8,974	39,459	2.300
1999	21,033	52,048	20,508	5,214	61,256	11,619	11,359	49,897	2.912
Maximum	22,278	63,500	39,310	9,508	88,833	23,078	22,205	66,628	4.044
Minimum	21,033	46,545	5,125	1,315	48,433	1,150	8,974	39,459	2.300
Average	21,493	56,440	18,182	5,462	70,068	8,779	15,586	54,482	3.257

Table 56. Consumptive Use of Applied Irrigation Water for Hydrologic Unit No. IV

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	58,607	155,373	41,276	16,110	198,760	15,401	49,558	149,202	3.391
1982	58,861	149,525	54,934	20,125	184,689	19,087	46,054	138,635	3.138
1983	59,107	140,505	73,389	22,376	168,608	35,716	42,049	126,559	2.853
1984	59,358	167,299	18,302	5,397	231,099	5,279	57,642	173,457	3.893
1985	59,612	158,033	34,276	11,926	208,560	14,096	52,025	156,535	3.499
1986	59,861	150,538	60,358	20,159	180,890	29,187	41,465	139,425	3.022
1987	60,111	161,243	44,582	17,233	199,806	18,285	45,806	154,000	3.324
1988	60,367	158,091	35,717	11,031	204,047	10,851	46,785	157,262	3.380
1989	60,616	158,893	36,876	13,027	202,404	13,208	46,418	155,986	3.339
1990	60,866	164,085	40,071	12,705	210,062	14,995	48,179	161,883	3.451
1991	61,119	164,077	43,302	13,946	202,557	22,136	42,299	160,258	3.314
1992	61,375	157,090	35,808	13,952	193,123	14,774	40,329	152,794	3.147
1993	61,629	157,230	59,582	17,209	188,916	32,961	39,449	149,467	3.065
1994	61,891	155,406	38,686	10,518	195,481	12,792	40,819	154,662	3.158
1995	62,142	150,842	81,310	22,976	172,498	43,517	36,008	136,490	2.776
1996	62,413	164,182	55,654	18,041	191,028	25,632	35,335	155,693	3.061
1997	62,664	160,038	36,032	10,450	195,533	21,387	36,167	159,366	3.120
1998	62,929	137,949	117,467	29,159	142,113	69,961	26,217	115,896	2.258
1999	63,185	156,504	64,765	16,835	182,488	37,415	33,695	148,793	2.888
Maximum	63,185	167,299	117,467	29,159	231,099	69,961	57,642	173,457	3.893
Minimum	58,607	137,949	18,302	5,397	142,113	5,279	26,217	115,896	2.258
Average	60,880	156,153	51,178	15,957	192,245	24,036	42,437	149,809	3.162

Table 57. Consumptive Use of Applied Irrigation Water for Hydrologic Unit No. V

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	66,707	164,332	38,786	15,173	213,084	13,081	53,271	159,813	3.194
1982	66,850	158,259	51,810	18,230	200,041	16,837	50,010	150,031	2.992
1983	66,993	148,303	77,043	27,514	172,556	32,971	43,138	129,418	2.576
1984	67,138	177,003	15,106	4,631	246,243	4,018	61,559	184,684	3.668
1985	67,281	167,158	29,716	10,428	223,897	11,093	55,972	167,925	3.328
1986	67,423	159,481	54,501	20,985	192,351	22,197	44,237	148,114	2.853
1987	67,565	169,997	42,791	17,402	211,930	15,764	48,738	163,192	3.137
1988	67,709	166,749	36,112	10,856	216,508	10,867	49,790	166,718	3.198
1989	67,852	167,950	37,884	12,724	215,580	13,250	49,576	166,004	3.177
1990	67,994	172,938	41,362	13,597	221,293	13,944	50,887	170,406	3.255
1991	68,137	172,278	42,585	17,234	209,472	18,250	43,955	165,517	3.074
1992	68,168	163,176	35,787	14,832	200,419	13,497	42,055	158,364	2.940
1993	68,199	162,925	60,809	22,646	189,519	29,454	39,764	149,755	2.779
1994	68,230	159,849	42,075	11,956	199,802	13,613	41,919	157,883	2.928
1995	68,263	154,182	77,360	25,344	174,049	36,312	36,508	137,541	2.550
1996	68,290	165,425	54,062	20,296	190,587	20,657	35,929	154,658	2.791
1997	68,322	159,619	33,022	12,497	193,192	17,090	36,410	156,782	2.828
1998	68,352	137,056	111,072	31,514	138,552	60,200	26,082	112,470	2.027
1999	68,382	153,455	59,265	19,958	175,247	27,929	32,988	142,259	2.563
Maximum	68,382	177,003	111,072	31,514	246,243	60,200	61,559	184,684	3.668
Minimum	66,707	137,056	15,106	4,631	138,552	4,018	26,082	112,470	2.027
Average	67,782	162,112	49,534	17,254	199,175	20,580	44,357	154,818	2.940

Table 58. Consumptive Use of Applied Irrigation Water for Hydrologic Unit No. VI

Calendar Year	Total Cropped Acreage (acres)	Total Crop ETc (af)	Total Rainfall (af)	Effective Rainfall (af)	Gross Applied Irrigation Water (af)	Percolation of Rainfall (af)	Percolation of Irrigation Water (af)	Net Applied Irrigation Water (af)	Gross Applied Irrigation Water (af/acre)
1981	68,961	170,853	35,187	12,212	226,630	12,289	56,657	169,973	3.286
1982	68,759	163,535	46,983	14,531	212,862	15,805	53,215	159,647	3.096
1983	68,561	151,947	77,128	28,949	175,712	31,805	43,927	131,785	2.563
1984	68,360	180,747	18,798	5,679	250,097	6,545	62,524	187,573	3.659
1985	68,158	169,624	26,695	8,608	230,022	9,828	57,505	172,517	3.375
1986	67,960	161,068	50,966	18,814	197,591	20,744	45,458	152,133	2.907
1987	67,757	169,854	41,218	15,706	214,109	15,860	49,256	164,853	3.160
1988	67,554	165,224	34,340	9,191	216,723	11,356	49,854	166,869	3.208
1989	67,354	167,139	33,116	9,405	219,082	10,765	50,394	168,688	3.253
1990	67,155	171,122	41,972	12,879	219,785	14,625	50,553	169,232	3.273
1991	66,953	169,348	41,288	15,953	207,272	17,291	43,513	163,759	3.096
1992	68,283	160,158	34,710	13,438	198,254	13,802	41,621	156,633	2.903
1993	69,613	161,768	60,911	23,914	186,275	28,688	39,107	147,168	2.676
1994	70,942	159,393	45,519	12,631	198,313	15,725	41,636	156,677	2.795
1995	72,274	155,515	76,483	26,883	173,818	33,991	36,495	137,323	2.405
1996	73,600	166,840	54,586	19,906	193,147	21,697	36,556	156,591	2.624
1997	74,930	161,678	31,844	12,300	196,324	15,776	37,130	159,194	2.620
1998	76,259	141,837	110,578	36,556	138,347	54,330	26,149	112,198	1.814
1999	77,588	159,376	60,133	19,874	183,270	27,996	34,605	148,665	2.362
Maximum	77,588	180,747	110,578	36,556	250,097	54,330	62,524	187,573	3.659
Minimum	66,953	141,837	18,798	5,679	138,347	6,545	26,149	112,198	1.814
Average	70,054	163,528	48,550	16,707	201,981	19,943	45,061	156,920	2.899

6.2.3.2.2 Municipal, Public Water System, Rural Domestic, and Dairy Groundwater Pumpage

Basic Methodology. Municipal and industrial (M&I), public water system, rural domestic, dairy, nursery, golf course, and other miscellaneous groundwater pumpage in the District was estimated for each year of the base period and for each hydrologic unit using a variety of methods. Data used to estimate the water demand included metered groundwater pumping records (Cal Water Service Company (Cal Water), City of Tulare, etc.), demand estimates based on service connections and categories of facilities, population and dwelling unit density estimates, interviews with various industrial facility managers (nursery, food processing, and packing plants, etc.), and information provided by the County Agricultural Commissioners Office and the Dairy Advisor.

Urban Demand. Urban demand, also referred to as M & I demand in the District, is the demand on groundwater that occurs in the incorporated cities (Visalia, Tulare, Farmersville, Exeter, Ivanhoe) and in the unincorporated areas of the District served by a municipal water purveyor. All other water demand in the unincorporated areas of the District is met by small public water systems regulated by the local environmental health departments and are accounted for separately as described below.

Urban demand was estimated for each hydrologic unit and for each year of the base period by compiling actual pumpage records for wells operated by the municipal water purveyors. For the most part, the tabulation of the pumpage records was straightforward. Apportionment of groundwater pumpage to the appropriate hydrologic unit involved knowledge of the location of individual wells (e.g., for the 100 or so wells in the Visalia District of Cal Water) and wells operated by the cities of Exeter and Ivanhoe, which are not strictly in the District but have wells within the District. Accuracy of the metered pumpage records are believed to be within 5 percent and any discrepancies of over or under reporting by metering devices is assumed to balance out. Pumpage records were commonly available on a monthly basis (although not in all cases). Where calendar year records were available, they were not adjusted to a water year basis because the overall volumes being considered were relatively small. Urban demand is satisfied by groundwater pumpage and does not include surface water sources.

A summary of the urban demand groundwater pumping over the base period and for each hydrologic unit is tabulated on Table 59 - Urban Groundwater Pumpage. As indicated, urban demand ranged from about 23,600 to 42,500 afy over the base period and averaged about 32,500 afy.

Table 59. Urban Groundwater Pumpage
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	325	2,305	12,294	1,717	7,525	0	**24,167**
1982	336	2,173	11,588	1,753	7,780	0	**23,630**
1983	347	2,288	12,201	1,891	8,036	0	**24,762**
1984	358	2,751	14,674	2,242	8,291	0	**28,317**
1985	369	2,720	14,506	2,128	8,547	0	**28,270**
1986	380	2,932	15,635	2,243	8,802	0	**29,992**
1987	391	3,046	16,246	2,405	9,058	0	**31,146**
1988	402	2,991	15,950	1,871	9,314	0	**30,527**
1989	699	2,953	15,748	2,495	9,370	0	**31,265**
1990	777	3,068	16,363	2,532	10,207	0	**32,947**
1991	235	2,881	15,366	2,416	10,747	0	**31,646**
1992	349	3,153	16,818	2,548	10,460	0	**33,329**
1993	676	3,185	16,984	2,692	10,011	0	**33,547**
1994	276	3,411	18,190	2,846	13,515	0	**38,237**
1995	210	3,552	18,943	2,685	11,470	0	**36,860**
1996	475	3,745	19,974	2,810	12,640	0	**39,644**
1997	653	3,897	20,786	2,951	12,995	0	**41,283**
1998	414	3,480	18,559	2,758	9,652	0	**34,863**
1999	415	3,977	21,208	2,947	13,912	0	**42,458**
Maximum	**777**	**3,977**	**21,208**	**2,951**	**13,912**	**0**	**42,458**
Minimum	**210**	**2,173**	**11,588**	**1,717**	**7,525**	**0**	**23,630**
Average	**426**	**3,079**	**16,423**	**2,417**	**10,123**	**0**	**32,468**
	City of Ivanhoe	Visalia (15%)	Visalia (80%)	Visalia (5%) Farmersville	City of Tulare		

Public Water System Demand. Analysis of annual water demand for small, regulated public water systems in both Kings and Tulare Counties was accomplished through an inspection of the listings of approximately 500 such systems available from the County of Tulare Health and Human Services Agency. The listings of water systems provided information as the facility identification/name, general location within the respective counties, a code related to the approximate number of service connections for the facility, and a contact name and phone number for the facility. Typical groupings of facility types common to the lists included mutual water companies, schools, mobile home parks, golf courses, county facilities such as civic centers, road yards, etc., motels, livestock sales yards, and miscellaneous industries such as nurseries, food processing facilities, packing houses, etc. The location of small public water systems is shown on Plate 61 - Small Water Systems Location Map.

Of the approximate 500 public water systems in both counties, approximately 80 were located in the Tulare, Visalia, and Farmersville areas. As indicated on Table 60 - Assigned Annual Water Duty and Water Demand, Public Water System, annual water demand for the approximate 80 public water systems was approached by itemizing the number of facilities by service code and assigning an approximate water duty factor based on the number of service connections. Service codes 4644, 4621, and 4622 were typical of very small water systems such as a well serving about five single-family residences and small mutual water systems with up to 100 service connections.

Table 60. Assigned Annual Water Duty and Water Demand, Public Water System
(in acre-feet per year)

Service Code	Assigned Water Duty	Number of Facilities/Total Demand					
		Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI
4644	10			6 / 60	1 / 10	5/ 50	1/ 10
4622	20			2 / 40		2 / 40	
4621	65			4 / 260			
4620	150			5 / 750	1 / 150		5 / 1,000
4645	200			17 / 3,400	2 / 400	7 / 1,400	
4633	25			6 / 150			
Total Demand (afy):		**0**	**0**	**4,660**	**560**	**1,690**	**1,010**
Golf Course	300	0.5 / 150		3 / 900	1 / 300	1 / 300	
		Sawtooth (9 Holes: Built 1998)		Valley Oaks (27 holes in 1996) Visalia County Club Oak Patch (9 holes)	Tulare G.C.	Sierra View G.C.	
Nursery	500	1 / 500					
		Monrovia Nursery (1991 on)					

Service code 4620 was typical of mobile home parks, service code 4645 typical of schools, light industry, food processing and packing houses, and service code 4633 typical of transient facilities such as motels, apartment complexes, etc. Golf courses (five total in the District) were itemized separately in that water use for golf courses is generally known. It was assumed that there was no material change in the number or distribution of public water systems over the duration of the base period. Water duties were assigned based on the average of the service connections for each category (exclusive of golf course water demand, which was estimated at 300 afy per facility) and was set at 1 afy for each service connection. Based on location in the District, the public water system demand was then apportioned to each hydrologic unit. The increase in small water system groundwater demand over the base period was indexed to Tulare County population. As indicated, the annual demand about 6,700 afy is relatively small.

Rural Domestic Water Demand. Rural domestic water demand in the District consists of the demand of residences not served by a municipal connection, mutual water company, or other small public water system. In some cases, demand is met through wells that serve adjacent agricultural lands as well as the residence, but such residences can and often are alternatively served by small-capacity individual wells.

To our knowledge, there is no District-specific data on the number of rural residential dwelling units such as might be contained in a County Water Master Plan or similar document. Similarly, there is no District-specific population or census information over the base period or for any other time from which the population of the incorporated areas can be subtracted to arrive at population data, population per dwelling unit, and rural domestic per capita water consumption. Rural residential units (EDAW, 1998) can be described as "ranchette" type homes of several acres in size with population per dwelling unit of about 3. Net water demand for such dwelling units is on the order of 2.0 afy.

Table 61. Summary of Small Water System Groundwater Demand
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	0	0	3,195	384	1,159	693	**5,431**
1982	0	0	3,279	394	1,189	711	**5,573**
1983	0	0	3,363	404	1,220	729	**5,716**
1984	0	0	3,447	414	1,250	747	**5,858**
1985	0	0	3,531	424	1,280	765	**6,000**
1986	0	0	3,614	434	1,311	783	**6,142**
1987	0	0	3,698	444	1,341	802	**6,285**
1988	0	0	3,782	454	1,372	820	**6,428**
1989	0	0	3,866	465	1,402	838	**6,571**
1990	0	0	3,950	475	1,432	856	**6,713**
1991	0	0	4,021	483	1,458	871	**6,833**
1992	0	0	4,092	492	1,484	887	**6,955**
1993	0	0	4,163	500	1,510	902	**7,075**
1994	0	0	4,234	509	1,535	918	**7,196**
1995	0	0	4,305	517	1,561	933	**7,316**
1996	0	0	4,376	526	1,587	948	**7,437**
1997	0	0	4,447	534	1,613	964	**7,558**
1998	0	0	4,518	543	1,638	979	**7,678**
1999	0	0	4,589	551	1,664	995	**7,799**
Maximum	0	0	**4,589**	**551**	**1,664**	**995**	**7,799**
Minimum	0	0	**3,195**	**384**	**1,159**	**693**	**5,431**
Average	0	0	**3,919**	**471**	**1,421**	**850**	**6,661**

Given the lack of data on the density of such dwelling units in the District, low altitude aerial photographs were used to derive a density of such units throughout the unincorporated areas of the District. The assumption was that the density of the rural dwelling units are normally distributed throughout the District. Ten "study areas" of 5 square miles each were randomly selected in the District, enlarged for inspection, and the number of rural dwelling units tabulated (Plate 62 - Rural Domestic Water Demand Analysis Map). The density of units ranged from about 7.8 on the east side of the District to 1.7 on the west side. The densities were then applied to the proportional size of each hydrologic unit (exclusive of the incorporated areas) and a net "water duty" of 2.0 afy applied to the density ratio.

Unlike the small, public water system demand estimates that were indexed to population changes in Tulare County over the last 20 years, it was felt that the density of rural domestic dwellings has not changed significantly in the District over the last 20 years, other than being replaced by urban sprawl. Rural domestic demand was estimated to be on the order of 1,800 afy using this method. Table 62 - Rural Domestic Groundwater Demand, presents the rural domestic demand figures for each hydrologic unit over the base period.

Table 62. Rural Domestic Groundwater Demand

	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
Houses Per Square Mile	7.81	1.70	2.60	1.92	1.70	1.80	2.27
Percentage of Total	45	10	15	11	10	10	100
Rural Domestic Demand Per Year (af)	835	182	278	205	182	193	1,876

Dairy and Related Demand. The dairy industry and related processing and distribution facilities are an important and growing industry in Tulare and Kings Counties, and water use associated with this land use is not insignificant. A number of publications and periodicals provide statistics of the dairy industry in the District (Shultz, 1997). Cow and herd census information is available for the last 50+ years. Tulare County dairy farms are more concentrated around the City of Tulare where several large creameries are located (Dairyman's, Land 'O Lakes, etc.). The Land 'O Lakes creamery serves over 200 dairy farms within a 45-mile radius and receives about 12 million pounds of milk daily. As of 2000, about 33 percent of the total butter and milk powder produced in California is manufactured annually by this Tulare County creamery alone.

Estimates of net water consumed by the dairy industry (farms) in the District were based on cow census records for the respective Kings and Tulare county areas. Such information is available on an annual basis from numerous sources. Since there are no cow census records specific to the District, it was assumed that dairy farms were normally distributed within the District. This assumption may not be strictly valid given the aforementioned clustering of dairy farms in and around the City of Tulare.

Table 63 - Dairy Land Use Analysis, presents the relative percentages of dairy farm acreages in the two counties as well as estimates of dairy cows in the District based on the land use data. The population of related livestock (poultry, swine, sheep, etc.) is also shown, and were not considered in the water demand estimates due to the small numbers.

Table 63. Dairy Land Use Analysis

	Tulare County (acres)	**Tulare County & District (acres)**	**Tulare & District / Tulare**	**Source**
2000	82,915	42,388	51%	County of Tulare, 2001 Census
1999	16,132	7,619	47%	DWR Land use
1993	11,910	6,102	51%	DWR Land use
	Kings County (acres)	**Kings County & District (acres)**	**Kings & District / Kings**	
1991	3,993	1,889	47%	DWR Land use
1996	5,473	2,366	43%	DWR Land use
	Number in Tulare County	**Number in Tulare County & District**	**Tulare & District / Tulare**	
Cows	326,158	140,005	43%	County of Tulare, 2001 Census
Poultry	2,104	240	11%	County of Tulare, 2001 Census
Swine	1,268	430	34%	County of Tulare, 2001 Census
Equine	642	154	24%	County of Tulare, 2001 Census
Goats	17	17	100%	County of Tulare, 2001 Census

The relative percentage of dairy farm acreage and estimated cow population data were then applied to annual cow census data to arrive at the number of dairy cows in the District for each year of the base period. From these data (refer to Table 64 - Summary of Dairy Cow Population and Water Use Estimates), a net water duty factor was applied based on information of daily cow water consumption and water use (facility wash water, etc.). Conversations with the Kings County Dairy Advisor (Ms. Carole Collar) indicate the gross daily water use per cow is on the order of 125 gallons per day (gpd). Net water use (after consideration for the recycling of the water for use on adjacent agricultural lands) is considered to be on the order of 75 gpd. Using these values, dairy farm water use in the District has ranged from about 4,100 afy in 1981 (estimated cow census of about 50,000 head) to slightly greater than 16,000 afy in 1999 (estimated cow census of about 193,000). Distribution of the dairy water demand (all assumed to be from pumped groundwater) by hydrologic unit was based on the acreage of dairy farms in the District. As indicated in Table 65 - Summary of Dairy Water Demand, most of the dairy farm demand occurs in Hydrologic Unit Nos. IV, V, and VI.

Table 64. Summary of Dairy Cow Population and Water Use Estimates

Calendar Year	Cows in Kings County	Cows in Kings County & District	Cows in Tulare County	Cows in Tulare County & District	Total Cows in District	Water Use per Cow (gpd)*	Water Use Per Day (mgd)	Water Use Per Year (mgd)	Water Use Per Year (af)
1981	49,149	22,247	54,895	27,373	49,620	75	3.72	1,358	4,169
1982	52,625	23,820	69,746	34,778	58,598	75	4.39	1,604	4,923
1983	56,100	25,393	84,596	42,183	67,576	75	5.07	1,850	5,677
1984	59,575	26,966	99,447	49,588	76,555	75	5.74	2,096	6,431
1985	63,050	28,539	114,298	56,994	85,533	75	6.41	2,341	7,186
1986	66,525	30,112	129,149	64,399	94,511	75	7.09	2,587	7,940
1987	70,000	31,685	144,000	71,804	103,489	75	7.76	2,833	8,694
1988	71,000	32,138	141,000	70,308	102,446	75	7.68	2,804	8,607
1989	77,000	34,854	178,000	88,758	123,612	75	9.27	3,384	10,385
1990	77,000	34,854	189,000	94,243	129,097	75	9.68	3,534	10,846
1991	78,000	35,306	200,000	99,728	135,034	75	10.13	3,697	11,344
1992	78,000	35,306	217,000	108,205	143,511	75	10.76	3,929	12,057
1993	82,758	37,460	210,798	105,112	142,572	75	10.69	3,903	11,978
1994	91,156	41,261	232,674	116,021	157,282	75	11.80	4,306	13,213
1995	101,716	46,041	265,346	132,312	178,354	75	13.38	4,882	14,984
1996	98,772	44,709	249,429	124,375	169,084	75	12.68	4,629	14,205
1997	104,751	47,415	292,509	145,857	193,272	75	14.50	5,291	16,237
1998	108,226	48,988	300,921	144,394	193,382	75	14.50	5,294	16,246
1999	111,701	50,561	309,334	142,931	193,492	75	14.51	5,297	16,255
Maximum	111,701	50,561	309,334	145,857	193,492	75	14.5	5,297	16,255
Minimum	49,149	22,247	54,895	27,373	49,620	75	3.7	1,358	4,169
Average	78,795	35,666	183,271	90,493	126,159	75	9.5	3,454	10,559

Table 65. Summary of Dairy Water Demand
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	Entire District
1981	0	570	407	1,060	976	1,156	4,169
1982	0	673	481	1,252	1,153	1,365	4,923
1983	0	776	554	1,444	1,329	1,574	5,677
1984	0	879	628	1,635	1,506	1,783	6,431
1985	0	982	702	1,827	1,682	1,992	7,186
1986	0	1,085	775	2,019	1,859	2,201	7,940
1987	0	1,188	849	2,211	2,036	2,410	8,694
1988	0	1,176	840	2,189	2,015	2,386	8,607
1989	0	1,419	1,014	2,641	2,431	2,879	10,385
1990	0	1,482	1,059	2,758	2,539	3,007	10,846
1991	0	1,550	1,108	2,885	2,656	3,145	11,344
1992	0	1,648	1,177	3,066	2,823	3,343	12,057
1993	0	1,637	1,170	3,046	2,804	3,321	11,978
1994	0	1,806	1,290	3,360	3,094	3,663	13,213
1995	0	2,048	1,463	3,810	3,508	4,154	14,984
1996	0	1,941	1,387	3,612	3,326	3,938	14,205
1997	0	2,219	1,585	4,129	3,802	4,502	16,237
1998	0	2,220	1,586	4,131	3,804	4,504	16,246
1999	0	2,222	1,587	4,134	3,806	4,507	16,255
Maximum	0	2,222	1,587	4,134	3,806	4,507	16,255
Minimum	0	570	407	1,060	976	1,156	4,169
Average	0	1,449	1,035	2,695	2,482	2,939	10,599

6.2.3.2.3 Agricultural Pumpage

Methods to estimate the annual volumes of groundwater pumpage to meet the irrigation demands of an area typically include tabulation of meter records, conversion of energy data (which in turn requires pumping plant efficiency and water level [lift] assumptions), and/or analyses of consumptive use data. With the exception of municipal wells in the District (e.g., Cal Water), there is no formal tabulation of meter records to estimate groundwater pumpage in the District. It is likely that the majority of agricultural wells in the District do not have totalizing flow meters, although it is recognized that some agricultural pumpers may keep detailed meter records of groundwater use. Similarly, obtaining and analyzing energy records and well efficiency test data (if such records actually existed) for the more than 5,000 active irrigation wells in the District would be a significant undertaking, and likely not be very accurate given the wide range of plant efficiencies and lift.

Analyses of consumptive use data are generally the preferred method to estimate groundwater use. Total (gross) agricultural water demand in the District was estimated in the preceding section. If surface water were not a component of supply in the District, groundwater pumped to meet the irrigation demand would be equal to the gross agricultural water demand. However, as presented in Chapter 4, the conjunctive use of surface water provides an important source of water to meet, in part, the agricultural water demands in the District. Agricultural groundwater pumpage is accordingly equal to the total applied irrigation water demand less the surface water deliveries. The estimated amounts for each year of the base period are presented in Table 66 - Groundwater Pumpage for Irrigated Agriculture, for the entire District and for each of the six hydrologic units.

6.2.3.2.4 Total Groundwater Pumpage

Total groundwater pumpage in the District is the summation of agricultural demand, and M & I demand. M & I demand includes urban, small public water systems, rural domestic demand, dairy demand, nursery and golf course demand. The estimated volumes of groundwater pumpage are presented in Table 67 - Estimated Total Groundwater Pumpage. Average annual groundwater pumpage in the District over the base period was about 611,000 afy.

Table 66. Groundwater Pumpage for Irrigated Agriculture
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	District Total
1981	23,728	98,875	61,425	153,987	154,830	201,622	**694,467**
1982	18,659	42,824	35,035	66,075	48,656	138,854	**350,103**
1983	20,503	45,023	31,949	105,387	142,620	127,703	**473,185**
1984	30,106	98,381	66,372	161,758	146,944	185,572	**689,133**
1985	27,181	83,991	61,992	148,845	153,256	194,194	**669,459**
1986	23,102	51,218	44,592	93,991	33,890	138,942	**385,735**
1987	27,750	96,913	62,283	164,652	200,573	193,369	**745,540**
1988	29,328	99,720	61,916	169,633	151,961	196,236	**708,794**
1989	27,972	90,419	62,435	162,377	179,025	200,591	**722,819**
1990	30,329	104,401	66,580	186,273	220,888	218,761	**827,232**
1991	30,720	85,967	62,491	155,844	159,847	189,213	**684,082**
1992	29,411	93,013	62,063	165,846	179,012	195,401	**724,746**
1993	26,115	49,312	48,515	97,649	28,410	123,740	**373,741**
1994	28,743	87,049	58,803	163,913	163,405	192,637	**694,550**
1995	16,659	22,986	36,564	54,497	38,650	99,817	**269,173**
1996	27,120	58,010	50,056	99,481	48,229	130,619	**413,515**
1997	28,773	65,133	50,390	104,045	83,709	145,016	**477,066**
1998	15,673	6,773	21,318	36,251	12,753	83,679	**176,447**
1999	29,077	74,352	47,114	128,087	83,922	155,946	**518,498**
Maximum	**30,720**	**104,401**	**66,580**	**186,273**	**220,888**	**218,761**	**827,232**
Minimum	**15,673**	**6,773**	**21,318**	**36,251**	**12,753**	**83,679**	**176,447**
Average	**25,839**	**71,282**	**52,205**	**127,294**	**117,399**	**163,785**	**557,804**

Table 67. Estimated Total Groundwater Pumpage

(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	District Total
1981	24,888	101,932	78,349	157,653	164,972	203,664	**731,459**
1982	19,830	45,852	51,411	69,979	59,260	141,123	**387,455**
1983	21,685	48,269	49,095	109,631	153,687	130,199	**512,565**
1984	31,299	102,193	86,149	166,554	158,473	188,295	**732,964**
1985	28,385	87,875	81,759	153,729	165,247	197,144	**714,139**
1986	24,317	55,417	65,644	99,192	46,344	142,119	**433,033**
1987	28,976	101,329	84,104	170,217	213,490	196,774	**794,890**
1988	30,565	104,069	83,516	174,652	165,144	199,635	**757,580**
1989	29,506	94,973	84,091	168,483	192,710	204,501	**774,264**
1990	31,941	109,133	88,980	192,543	235,548	222,817	**880,962**
1991	32,290	90,580	84,014	162,133	175,190	193,422	**737,630**
1992	31,095	97,996	85,178	172,457	194,261	199,824	**780,812**
1993	28,126	54,316	71,860	104,392	43,217	128,156	**430,066**
1994	30,354	92,448	83,545	171,133	182,031	197,411	**756,921**
1995	18,204	28,768	62,303	62,014	55,671	105,097	**332,057**
1996	28,930	63,878	76,971	106,934	66,264	135,698	**478,675**
1997	30,761	71,431	78,386	112,164	102,601	150,675	**546,019**
1998	17,572	12,655	47,159	44,188	28,329	89,355	**239,258**
1999	30,977	80,733	75,676	136,224	103,786	161,641	**589,036**
Maximum	**32,290**	**109,133**	**88,980**	**192,543**	**235,548**	**222,817**	**880,962**
Minimum	**17,572**	**12,655**	**47,159**	**44,188**	**28,329**	**89,355**	**239,258**
Average	**27,353**	**75,992**	**74,642**	**133,383**	**131,907**	**167,766**	**611,041**

Note: Includes pumpage for M & I, irrigated agricultural, rural domestic demand, small water system demand, and dairy demand.

6.2.3.3 Consumptive Use by Phreatophytes

Estimates of consumptive use by phreatophytes in the District were approached in several ways. First, land use data for 1981, 1991, and 1999 provide the acreage of riparian vegetation to which a unit water use factor (in afy per acre) could be applied (1958). Vegetative types and the density of growth within the riparian corridors of the District (typically in the rivers and canals west of U.S. Highway 99) however, are only generally known. Groundwater consumed by phreatophytes is dependent on many factors including species, vegetative density, climate (sunlight, wind, temperature, humidity), soil, and depth to and quality of groundwater. Therefore, use of this approach was not considered further.

Computer software can be used to search an image for pixels spectrally similar to specified areas such as a riparian corridor. However, photographic imagery for the District that could classify vegetation types within buffer zones of the rivers and canals were not available. Accordingly, low altitude air photos of the riparian corridor areas were enlarged and visually inspected for the presence and density of riparian habitats and phreatophytes. An example of this analysis is shown on Plate 63 - Phreatophyte/Riparian Vegetation Map. For the most part, the acreage of oak woodland and related phreatophytes was found to be quite low. For the purposes of this study the riparian corridors were mapped, acreages tabulated and 20 percent of the riparian land considered as phreatophytes demand. Table 68 - Riparian Vegetation by Hydrologic Unit provides a summary of the data and results of the analyses.

Table 68. Riparian Vegetation by Hydrologic Unit

Hydrologic Unit	Acres	Adjusted (20% Density)
I	682	136
II	453	91
III	211	42
IV	1,097	219
V	207	41
VI	145	29
District Total:	2,795	559

Notes:

- Riparian Vegetation totals from land use data.
- Vegetation classes combine NR (native riparian) and NV (native vegetation) types where appropriate.
- Values were spot-checked against air photos of the District to detect blunders in coding.

From the data contained in Table 68, a consumptive water use of 0.8 afy/acre was applied to determine annual volumes of demand by phreatophytes. The volumes of phreatophyte extractions were indexed directly to variation in precipitation at the Visalia station. Specifically, the values presented in Table 69 were multiplied by the percentage of rainfall for each year to calculate the values presented in Table 69. These data are presented on Table 69 - Summary of Phreatophytes Extractions. As indicted in this table, annual volumes of groundwater use by phreatophytes is on the order of 500 afy, and is a relatively small component of outflow in the water balance.

Table 69. Summary of Phreatophyte Extractions
(in acre-feet per year)

Calendar Year	Hydrologic Unit No. I	Hydrologic Unit No. II	Hydrologic Unit No. III	Hydrologic Unit No. IV	Hydrologic Unit No. V	Hydrologic Unit No. VI	District Total
1981	112	75	35	181	34	24	**461**
1982	108	73	33	175	33	23	**445**
1983	126	84	39	203	38	27	**517**
1984	176	117	54	283	53	37	**720**
1985	64	43	20	103	19	14	**262**
1986	81	54	25	130	24	17	**332**
1987	105	70	32	169	32	22	**432**
1988	108	72	33	174	32	23	**442**
1989	89	59	27	143	27	19	**365**
1990	48	32	15	77	14	10	**197**
1991	54	36	17	87	16	12	**223**
1992	109	73	34	176	33	23	**449**
1993	97	65	30	157	29	21	**399**
1994	119	80	37	192	36	25	**489**
1995	91	61	28	147	27	19	**374**
1996	162	108	50	260	49	34	**663**
1997	157	105	48	253	47	33	**644**
1998	94	63	29	151	28	20	**385**
1999	193	129	60	311	58	41	**792**
Maximum	**193**	**129**	**60**	**311**	**58**	**41**	**792**
Minimum	**48**	**32**	**15**	**77**	**14**	**10**	**197**
Average	**110**	**74**	**34**	**177**	**33**	**23**	**452**

6.2.3.4 Evaporative Losses

Evaporative water losses from the river and distributary systems, and in artificial recharge basins (when present) were considered in the overall water balance. Evaporation from the rivers and distributaries obviously occurs and can be estimated based on total surface area and pan evaporation data (e.g., at Lake Kaweah). Surface water delivery and conveyance loss estimates, based on watermaster records should, however, account for instream losses, much in the same way that losses related to riparian use is accounted for. Evaporation losses from the approximate 2,100 acres of artificial recharge basins in the District can be estimated by using the average number of days per year of full basin storage and a Winter/Spring season pan evaporation value. Data contained in Chapter 4 suggest about 35 days per year (on average) of full basin storage (i.e., maximum surface area for evaporative loss). Winter/Spring pan evaporation for the District is on the order of 0.1 inch per day. Evaporative losses in the District related to artificial recharge basins are estimated at about 500 afy. For the remainder of the network of rivers and canals an allowance of 1,000 afy has been assigned and apportioned to each hydrologic unit based on the relative percentage of conveyance losses presented in Chapter 4. This additional evaporative loss is consistent with B&E (1997) and is estimated at about 500 afy.

6.2.3.5 Exported Water

Exported water, as used in this report, is any groundwater that is pumped from within the District and transferred for use outside the District. Surface water that passes through the District (exits at designated spill points as discussed in the section describing surface water) is not considered an export per se since the surface water never reaches the zone of saturation. While incidental transfers of pumped groundwater are presumed to occur across the District boundaries to satisfy agricultural demands, for the most part such transfers are small (measured in the several of hundreds of afy) and assumed to balance back and forth in any given year. There are several notable exceptions however in Hydrologic Unit VI where both the Corcoran Irrigation District (CID) and the Melga Water District (MWD) pump groundwater from well fields within the District and deliver such water to lands west and southwest of the District. The significance of these transfers are discussed more fully below.

CID is known to have as many as a dozen wells within the District located north of the City of Corcoran that have a combined capacity in excess of 10,000 gpm. In years when significant amounts of surface water are available from the Kings River and/or the Kaweah River systems (such as occurred from about 1981 to 1986 and from about 1995 to 1999), the wells are not pumped significantly. Extractions in such years are typically on the order of perhaps 20,000 afy. In years when surface water supply is deficient, groundwater pumped has been in excess of 100,000 afy. Record data reviewed by the District indicate that over the base period, CID pumped an average of about 60,000 afy from these wells (0 af in 1983 to 148,000 af in 1991). The best estimate is that about 84 percent of this amount, or about 45,000 af on the average annual basis, was transferred to lands outside the District for beneficial use. It should be noted that such water transfers were beneficially used within the Kaweah basin as defined by the DWR; however, the water was transferred to lands that are outside the District an, strictly speaking, is an export.

The MWD similarly operates as many as six wells within the District in Hydrologic Unit VI and also pumps groundwater for deliveries to lands outside the District. We understand that the MWD wellfield has a capacity of about 5,000 gpm. Record data reviewed by the District over the base period indicate that about 4,700 afy has been transferred out of the District and that the pattern of such transfers is similar to that of the CID.

Such water transfers of CID and MWD, when considered in the overall water balance for Hydrologic Unit VI, create a significant additional deficit in the accounting of water use in this unit using the inventory method. The west side of the District, and particularly Hydrologic Unit VI, is known to be in overdraft and significantly so given the recognized chronic and persistent declines in groundwater elevations that have occurred over the base period and since the 1950s. The addition of up to 50,000 af on an average annual basis of water transferred out of the District adds significantly to the negative change of groundwater in storage values for this unit using the inventory method and is not consistent with the change of groundwater in storage calculated using the specific yield method, which is significantly greater. Either the specific yield method used to assess storage changes in this area of the District cannot accurately account for the confined nature of the aquifer (highly likely), or the inventory method does not fully account for surface water deliveries and pumped groundwater in this unit.

At this time, the issue of water transfers outside the District by CID and MWD is recognized to occur, but has been not specifically tabulated as "exports" from the District. The issue will be revisited in the development and calibration numerical model of the District, which should, in the model calibration process, be able to better represent storage changes in the areas of confined aquifers in the District. It should be noted that the extent of overdraft in the west side of the District presented later in this report, about 39,000 afy for Hydrologic Unit VI alone, represents the minimum average annual overdraft for this unit.

6.3 GROUNDWATER IN STORAGE

6.3.1 Background

Seasonal variations in the volumes of groundwater in storage in the District and each hydrologic unit were calculated for each year of the base period using the water level elevation contour maps (presented as part of Chapter 3) and the estimated specific yield values presented in Chapter 2. The changes in storage for the approximate 19-year base period from 1981 to 1999 were used to evaluate conditions of water supply surplus and deficiency, and in recognizing conditions of long-term overdraft.

As indicated in Table 16, using the specific yield method, there was an accumulated water supply deficiency of about 685,000 af over the 19-year base period, or approximately 36,000 afy. Most of the water supply deficiency, some 321,000 af (or about 17,000 afy) occurred in Hydrologic Unit No. VI. For the most part and given the accuracy of the estimates, Hydrologic Unit Nos. II through V show a slight deficit of from about 3,000 to 7,000 afy. Hydrologic Unit No. I shows a slight water supply deficit over the base period.

6.4 WATER BALANCE

6.4.1 General Statement

Using the inventory method, the total seasonal water demand, that is, the sum of all the components of outflow from the District, exceeded the sum of all the components of inflow during the 19-year base period. This resulted in an accumulated deficit of about 412,900 af during the base period, and a corresponding decrease of groundwater in storage. This accumulated deficit is equal to an average annual deficit of 21,700 afy. Table 70 - Estimated Seasonal Deep Percolation, Extractions, and Change in Storage, Entire District, presents the seasonal amounts of each component of deep percolation and extractions for the District as computed by the use of the equation of hydrologic equilibrium (the "inventory method"). Summary tables are also provided for each of the six hydrologic units as Tables 71 to 76 - Estimated Seasonal Deep Percolation, Extraction, and Changes in Storage, Hydrologic Units I through VI, respectively. Changes in the amount of groundwater in storage as calculated by the specific yield method are also presented for comparison. By this latter method, there was a seasonal decrease in the amount of groundwater in storage of about 36,000 afy, and an accumulated deficit of 684,600 af during the base period.

The seasonal amounts of changes in storage by the two methods differed in all cases, and these differences can be graphically presented as cumulative variations on Plate 42 - Cumulative Annual Change in Storage, Entire District, and on Plates 43 through 48 - Cumulative Annual Change in Storage, Hydrologic Units I through VI, respectively. Such differences are usual for several reasons: in any particular season, the amount of water entering the zone of saturation is not always equal to the amount of water originating as deep percolation and subsurface inflow. Typically, the estimated change in storage by the specific yield method provides a more muted seasonal response of storage change. Moreover, any inaccuracies in the estimated seasonal components of water supply, use, and disposal can cause appreciable variations in the amount of change of groundwater in storage. This is particularly true for those years or succession of years in which annual rainfall and surface water deliveries are significantly greater than the long-term average, such as occurred in 1998. In some cases, the inventory method simply does not or cannot account for the complexities in how recharge to the aquifers occur or in the routing of surface water deliveries for irrigated agriculture. In such cases, there is a fairly wide divergence in the cumulative storage changes between the two methods (cf. for Hydrologic Unit Nos. I, III, and V). In these cases, the inventory method is not accounting for sufficient recharge as is expressed in the water levels, likely due to imbalances between surface water deliveries and groundwater pumpage.

In the remaining hydrologic units (II, IV, and VI), the differences, however, appear to be minimal since the accumulated amounts derived from each method follow seasonal totals reasonably well, and the summations of both methods for the entire base period are nearly equal (particularly for the entire District). A summary table of the surplus and deficiency for the entire District and each hydrologic unit is provided in Table 77 - Summary of Comparative Change in Storage. Balancing of the equation of hydrologic equilibrium can be accomplished by adjusting values of individual components of inflow and outflow (e.g., subsurface inflow) to achieve a better match. No such adjustments have been made at this time.

Table 70. Estimated Deep Percolation, Extractions and Change in Storage, Entire District (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow						Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
									Groundwater Pumpage												
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	M & I	Irrigated Agriculture	Total Net Extraction	Extraction by Phreatophytes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	73.6	8.3	126.5	4.5	217.7	60.1	37.0	694.5	731.5	0.5	1.0	46.2	490.6	779.1	-288.5	-172.4	-288.5	-172.4	248.3
1982	13.7	126%	64.5	8.5	427.3	183.0	202.8	76.5	37.4	350.1	387.5	0.4	1.0	32.2	962.7	421.1	541.6	486.8	253.1	314.4	771.3
1983	16.1	148%	61.8	8.8	433.0	304.9	177.3	149.5	39.4	473.2	512.6	0.5	1.0	48.9	1,135.3	562.9	572.3	329.1	825.5	643.5	1,402.0
1984	6.1	56%	87.0	9.1	242.3	60.3	248.8	22.3	43.8	689.1	733.0	0.7	1.0	38.7	669.7	773.4	-103.7	-87.0	721.8	556.5	516.8
1985	7.2	66%	47.1	9.4	163.8	22.4	224.7	55.9	44.7	669.5	714.1	0.3	1.0	16.1	523.3	731.5	-208.3	-118.2	513.5	438.3	329.9
1986	13.9	128%	45.1	9.6	335.9	99.4	177.7	113.1	47.3	385.7	433.0	0.3	1.0	24.8	780.8	459.1	321.7	209.6	835.2	648.0	815.0
1987	8.2	75%	54.3	10.0	77.1	2.8	195.0	77.9	49.4	745.5	794.9	0.4	1.0	8.8	417.0	805.1	-388.1	-279.3	447.1	368.7	183.9
1988	9.4	86%	35.9	10.2	97.2	3.7	198.9	46.8	48.8	708.8	757.6	0.4	1.0	12.5	392.8	771.5	-378.8	-246.5	68.3	122.2	184.5
1989	8.3	76%	36.8	10.6	87.4	0.4	198.1	53.7	51.4	722.8	774.3	0.4	1.0	23.0	386.9	798.6	-411.7	-426.0	-343.4	-303.8	214.3
1990	5.8	53%	53.5	10.6	48.9	0.1	202.5	63.8	53.7	827.2	881.0	0.2	1.0	11.9	379.5	894.0	-514.6	-528.1	-857.9	-832.0	141.2
1991	8.7	80%	59.9	10.9	111.9	0.8	176.3	83.4	53.5	684.1	737.6	0.2	1.0	18.1	443.3	757.0	-313.7	-222.6	-1,171.6	-1,054.6	252.3
1992	9.2	84%	62.9	10.5	68.3	1.1	168.1	58.6	56.1	724.7	780.8	0.4	1.0	9.3	369.5	791.6	-422.1	-285.8	-1,593.8	-1,340.4	148.4
1993	12.7	117%	48.1	11.1	274.2	48.7	161.0	134.7	56.3	373.7	430.1	0.4	1.0	13.8	677.8	445.3	232.6	-37.7	-1,361.2	-1,378.1	550.1
1994	7.8	72%	36.6	11.8	95.3	0.9	168.5	61.0	62.4	694.6	756.9	0.5	1.0	13.3	374.2	771.7	-397.5	132.1	-1,758.7	-1,246.0	191.7
1995	17.6	161%	59.8	12.2	352.4	140.4	147.9	172.2	62.9	269.2	332.1	0.4	1.0	12.4	884.8	345.9	538.9	288.4	-1,219.8	-957.5	866.7
1996	11.5	106%	71.5	12.1	262.9	86.1	146.2	102.9	65.2	413.5	478.7	0.7	1.0	35.1	681.8	515.5	166.3	100.7	-1,053.5	-856.8	528.7
1997	11.2	103%	68.6	12.5	273.6	90.1	149.8	83.6	69.0	477.1	546.0	0.6	1.0	50.7	678.2	598.4	79.8	-20.0	-973.7	-876.9	759.7
1998	22.1	203%	49.2	12.6	338.1	190.8	107.2	275.0	62.8	176.4	239.3	0.4	1.0	24.9	972.9	265.5	707.4	436.9	-266.4	-440.0	927.9
1999	9.2	84%	39.5	13.4	139.3	8.6	138.9	136.9	70.5	518.5	589.0	0.8	1.0	32.4	476.7	623.2	-146.5	-244.6	-412.9	-684.6	266.0
Maximum	22.1	203%	87.0	13.4	433.0	304.9	248.8	275.0	70.5	827.2	881.0	0.8	1.0	50.7	1,135.3	894.0	707.4	486.8			
Minimum	5.8	53%	35.9	8.3	48.9	0.1	107.2	22.3	37.0	176.4	239.3	0.2	1.0	8.8	369.5	265.5	-514.6	-528.1			
Average	10.9	100%	55.6	10.6	208.2	65.7	179.3	96.2	53.2	557.8	611.0	0.5	1.0	24.9	615.7	637.4	-21.7	-36.0			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

Table 71. Estimated Deep Percolation, Extractions, and Change in Storage, Hydrologic Unit I (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow						Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
									Groundwater Pumpage												
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	M & I	Irrigated Agriculture	Total Net Extraction	Extraction by Phreatophytes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	13.2	0.0	12.1	0.0	8.2	3.9	1.2	23.7	24.9	0.1	0.1	17.7	37.3	42.8	-5.5	-2.7	-5.5	-2.7	248.3
1982	13.7	126%	11.9	0.0	23.8	0.0	7.6	5.3	1.2	18.7	19.8	0.1	0.1	27.8	48.5	47.8	0.7	9.6	-4.8	6.9	771.3
1983	16.1	148%	13.5	0.0	24.0	0.0	7.2	8.9	1.2	20.5	21.7	0.1	0.1	14.8	53.5	36.7	16.9	3.9	12.1	10.9	1,402.0
1984	6.1	56%	11.7	0.0	14.3	0.0	9.7	2.5	1.2	30.1	31.3	0.2	0.1	15.3	38.2	46.8	-8.6	-13.2	3.5	-2.3	516.8
1985	7.2	66%	8.8	0.0	13.9	0.0	8.8	5.0	1.2	27.2	28.4	0.1	0.1	11.1	36.4	39.6	-3.2	5.6	0.3	3.3	329.9
1986	13.9	128%	11.4	0.0	22.6	0.0	6.9	8.1	1.2	23.1	24.3	0.1	0.1	27.1	48.9	51.6	-2.7	-6.2	-2.4	-3.0	815.0
1987	8.2	75%	18.0	0.0	11.6	0.0	7.9	4.7	1.2	27.8	29.0	0.1	0.1	25.0	42.1	54.3	-12.1	-4.3	-14.5	-7.2	183.9
1988	9.4	86%	18.9	0.0	8.0	0.0	8.0	2.3	1.2	29.3	30.6	0.1	0.1	15.4	37.2	46.2	-9.0	-5.6	-23.4	-12.8	184.5
1989	8.3	76%	15.3	0.0	8.1	0.0	8.0	2.6	1.5	28.0	29.5	0.1	0.1	23.3	34.0	53.0	-19.0	-6.6	-42.4	-19.4	214.3
1990	5.8	53%	20.5	0.0	9.1	0.0	8.5	4.2	1.6	30.3	31.9	0.0	0.2	18.7	42.4	50.9	-8.5	-11.1	-50.9	-30.5	141.2
1991	8.7	80%	17.2	0.0	13.5	0.0	7.6	5.5	1.6	30.7	32.3	0.1	0.1	28.8	43.8	61.3	-17.5	9.2	-68.4	-21.2	252.3
1992	9.2	84%	22.4	0.0	12.6	0.0	7.2	3.6	1.7	29.4	31.1	0.1	0.2	35.1	45.8	66.5	-20.7	-6.2	-89.2	-27.4	148.4
1993	12.7	117%	12.7	0.0	19.4	0.0	7.1	8.2	2.0	26.1	28.1	0.1	0.1	32.7	47.5	61.0	-13.6	-12.7	-102.7	-40.2	550.1
1994	7.8	72%	8.6	0.0	15.6	0.0	7.2	4.1	1.6	28.7	30.4	0.1	0.2	29.2	35.5	59.9	-24.4	20.5	-127.1	-19.6	191.7
1995	17.6	161%	15.7	0.0	23.9	0.0	6.6	13.4	1.5	16.7	18.2	0.1	0.1	30.6	59.5	49.0	10.6	2.1	-116.5	-17.5	866.7
1996	11.5	106%	26.8	0.0	14.2	0.0	7.0	7.6	1.8	27.1	28.9	0.2	0.1	13.5	55.5	42.6	12.9	10.7	-103.6	-6.8	528.7
1997	11.2	103%	18.9	0.0	19.1	0.0	7.3	7.3	2.0	28.8	30.8	0.2	0.1	28.8	52.6	59.8	-7.2	-1.8	-110.8	-8.6	759.7
1998	22.1	203%	16.5	0.0	19.2	0.0	5.3	21.1	1.9	15.7	17.6	0.1	0.1	23.5	62.1	41.3	20.9	6.8	-90.0	-1.9	927.9
1999	9.2	84%	15.7	0.0	9.6	0.0	7.0	10.7	1.9	29.1	31.0	0.2	0.1	14.9	43.0	46.2	-3.1	-3.1	-93.1	-5.0	266.0
Maximum	22.1	203%	26.8	0.0	24.0	0.0	9.7	21.1	2.0	30.7	32.3	0.2	0.2	35.1	62.1	66.5	20.9	20.5			
Minimum	5.8	53%	8.6	0.0	8.0	0.0	5.3	2.3	1.2	15.7	17.6	0.0	0.1	11.1	34.0	36.7	-24.4	-13.2			
Average	10.9	100%	15.7	0.0	15.5	0.0	7.5	6.8	1.5	25.8	27.4	0.1	0.1	22.8	45.5	50.4	-4.9	-0.3			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

Table 72. Estimated Deep Percolation, Extractions, and Change in Storage, Hydrologic Unit II (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow						Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
									Groundwater Pumpage												
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	M & I	Irrigated Agriculture	Total Net Extraction	Extraction by Phreatophytes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	9.5	0.0	26.6	0.2	30.7	9.5	3.1	98.9	101.9	0.1	0.2	10.0	76.5	112.2	-35.7	-10.0	-35.7	-10.0	248.3
1982	13.7	126%	7.7	0.0	87.3	16.2	28.1	12.3	3.0	42.8	45.9	0.1	0.2	18.0	151.6	64.1	87.5	40.3	51.8	30.3	771.3
1983	16.1	148%	7.3	0.0	95.2	26.9	24.8	25.2	3.2	45.0	48.3	0.1	0.2	12.3	179.3	60.9	118.4	31.0	170.2	61.3	1,402.0
1984	6.1	56%	7.7	0.0	49.6	4.6	35.2	2.8	3.8	98.4	102.2	0.1	0.2	20.6	99.9	123.1	-23.1	-8.0	147.1	53.3	516.8
1985	7.2	66%	10.4	0.0	35.3	1.4	30.7	10.6	3.9	84.0	87.9	0.0	0.2	8.2	88.4	96.3	-7.9	-11.8	139.2	41.5	329.9
1986	13.9	128%	6.6	0.0	74.2	9.5	23.8	20.9	4.2	51.2	55.4	0.1	0.2	18.6	135.0	74.3	60.7	13.0	199.9	54.5	815.0
1987	8.2	75%	7.4	0.0	17.9	0.1	26.2	14.7	4.4	96.9	101.3	0.1	0.2	7.0	66.4	108.6	-42.2	-32.0	157.7	22.6	183.9
1988	9.4	86%	9.6	0.0	17.0	0.1	27.1	7.4	4.3	99.7	104.1	0.1	0.2	9.8	61.3	114.1	-52.8	-23.2	104.9	-0.6	184.5
1989	8.3	76%	9.5	0.0	20.3	0.0	26.7	9.0	4.6	90.4	95.0	0.1	0.2	8.9	65.5	104.2	-38.7	-44.0	66.2	-44.6	214.3
1990	5.8	53%	9.3	0.0	11.4	0.0	26.8	10.5	4.7	104.4	109.1	0.0	0.2	7.5	57.9	116.9	-58.9	-54.5	7.3	-99.2	141.2
1991	8.7	80%	10.4	0.0	26.8	0.1	23.6	12.9	4.6	86.0	90.6	0.0	0.2	6.1	73.7	97.0	-23.2	-13.1	-16.0	-112.3	252.3
1992	9.2	84%	11.4	0.0	14.6	0.1	22.4	8.1	5.0	93.0	98.0	0.1	0.2	2.0	56.6	100.3	-43.7	-26.4	-59.7	-138.7	148.4
1993	12.7	117%	10.6	0.0	46.9	4.3	21.4	22.6	5.0	49.3	54.3	0.1	0.2	9.6	105.8	64.2	41.6	16.6	-18.0	-122.1	550.1
1994	7.8	72%	13.2	0.0	21.2	0.1	22.6	9.8	5.4	87.0	92.4	0.1	0.2	1.1	66.9	93.9	-27.0	-18.1	-45.0	-140.2	191.7
1995	17.6	161%	23.3	0.0	74.7	12.5	19.6	29.5	5.8	23.0	28.8	0.1	0.2	1.8	159.6	30.8	128.7	64.0	83.7	-76.3	866.7
1996	11.5	106%	6.3	0.0	41.3	7.4	19.3	17.9	5.9	58.0	63.9	0.1	0.2	12.8	92.2	76.9	15.3	10.0	99.0	-66.2	528.7
1997	11.2	103%	14.3	0.0	53.9	7.5	20.5	14.3	6.3	65.1	71.4	0.1	0.2	17.5	110.5	89.2	21.3	-3.1	120.3	-69.4	759.7
1998	22.1	203%	13.1	0.0	74.1	15.8	14.5	46.4	5.9	6.8	12.7	0.1	0.2	8.7	163.8	21.6	142.2	46.7	262.5	-22.7	927.9
1999	9.2	84%	10.9	0.0	25.2	0.7	19.2	21.3	6.4	74.4	80.7	0.1	0.2	7.3	77.3	88.3	-11.0	-40.1	251.5	-62.9	266.0
Maximum	22.1	203%	23.3	0.0	95.2	26.9	35.2	46.4	6.4	104.4	109.1	0.1	0.2	20.6	179.3	123.1	142.2	64.0			
Minimum	5.8	53%	6.3	0.0	11.4	0.0	14.5	2.8	3.0	6.8	12.7	0.0	0.2	1.1	56.6	21.6	-58.9	-54.5			
Average	10.9	100%	10.5	0.0	42.8	5.7	24.4	16.1	4.7	71.3	76.0	0.1	0.2	9.9	99.4	86.1	13.2	-3.3			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

Table 73. Estimated Deep Percolation, Extractions, and Change in Storage, Hydrologic Unit III (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow						Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	Groundwater Pumpage: M & I	Groundwater Pumpage: Irrigated Agriculture	Groundwater Pumpage: Total Net Extraction	Extraction by Phreatophtyes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	18.7	4.7	10.6	0.0	19.3	5.9	16.9	61.4	78.3	0.0	0.1	1.6	59.3	80.1	-20.8	-17.9	-20.8	-17.9	248.3
1982	13.7	126%	20.7	4.9	32.4	4.2	17.9	7.1	16.4	35.0	51.4	0.0	0.1	9.3	87.3	60.9	26.4	47.1	5.6	29.3	771.3
1983	16.1	148%	23.5	5.1	32.9	7.6	16.2	15.0	17.1	31.9	49.1	0.0	0.1	4.5	100.2	53.8	46.5	13.5	52.1	42.7	1,402.0
1984	6.1	56%	33.7	5.3	18.6	2.1	22.2	1.2	19.8	66.4	86.1	0.1	0.1	5.2	83.0	91.5	-8.5	0.3	43.6	43.0	516.8
1985	7.2	66%	15.3	5.5	13.3	0.5	19.7	5.3	19.8	62.0	81.8	0.0	0.1	2.4	59.6	84.2	-24.6	-11.6	19.0	31.4	329.9
1986	13.9	128%	20.4	5.7	26.3	4.0	15.8	11.9	21.1	44.6	65.6	0.0	0.1	0.7	84.1	66.5	17.7	27.6	36.7	58.9	815.0
1987	8.2	75%	14.1	5.9	8.4	0.0	17.1	8.5	21.8	62.3	84.1	0.0	0.1	2.4	54.0	86.7	-32.6	-27.6	4.0	31.3	183.9
1988	9.4	86%	9.4	6.1	8.9	0.1	17.3	4.0	21.6	61.9	83.5	0.0	0.1	8.3	45.7	91.9	-46.2	-28.4	-42.2	2.9	184.5
1989	8.3	76%	16.4	6.2	8.4	0.0	17.1	4.9	21.7	62.4	84.1	0.0	0.1	5.0	53.0	89.2	-36.2	-26.6	-78.4	-23.8	214.3
1990	5.8	53%	12.9	6.3	7.1	0.0	17.6	5.6	22.4	66.6	89.0	0.0	0.1	9.2	49.4	98.4	-49.0	-51.3	-127.3	-75.1	141.2
1991	8.7	80%	12.1	6.4	8.5	0.0	15.3	7.4	21.5	62.5	84.0	0.0	0.1	7.9	49.7	92.0	-42.3	6.2	-169.6	-68.8	252.3
1992	9.2	84%	7.8	6.3	7.0	0.1	14.5	4.8	23.1	62.1	85.2	0.0	0.1	15.5	40.5	100.8	-60.3	-40.9	-230.0	-109.7	148.4
1993	12.7	117%	13.4	6.6	18.2	1.5	14.2	12.8	23.3	48.5	71.9	0.0	0.1	8.2	66.6	80.2	-13.6	11.3	-243.6	-98.5	550.1
1994	7.8	72%	9.2	6.9	10.3	0.0	14.4	5.0	24.7	58.8	83.5	0.0	0.1	10.2	45.7	93.9	-48.2	-6.0	-291.7	-104.4	191.7
1995	17.6	161%	7.4	7.0	23.5	5.4	12.7	15.4	25.7	36.6	62.3	0.0	0.1	12.0	71.5	74.4	-2.9	23.0	-294.7	-81.5	866.7
1996	11.5	106%	17.1	7.0	17.8	3.1	12.1	9.5	26.9	50.1	77.0	0.0	0.1	8.6	66.6	85.6	-19.0	-9.2	-313.7	-90.6	528.7
1997	11.2	103%	33.8	7.3	17.0	3.6	12.3	7.8	28.0	50.4	78.4	0.0	0.1	6.1	81.8	84.6	-2.8	18.2	-316.5	-72.5	759.7
1998	22.1	203%	21.9	7.4	23.7	6.8	9.0	23.1	25.8	21.3	47.2	0.0	0.1	5.0	91.9	52.2	39.7	47.0	-276.8	-25.5	927.9
1999	9.2	84%	13.3	7.7	11.1	0.2	11.4	11.6	28.6	47.1	75.7	0.1	0.1	5.5	55.2	81.4	-26.2	-33.0	-303.0	-58.5	266.0
Maximum	22.1	203%	33.8	7.7	32.9	7.6	22.2	23.1	28.6	66.6	89.0	0.1	0.1	15.5	100.2	100.8	46.5	47.1			
Minimum	5.8	53%	7.4	4.7	7.0	0.0	9.0	1.2	16.4	21.3	47.2	0.0	0.1	0.7	40.5	52.2	-60.3	-51.3			
Average	10.9	100%	16.9	6.2	16.0	2.1	15.6	8.8	22.4	52.2	74.6	0.0	0.1	6.7	65.5	81.5	-15.9	-3.1			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

Table 74. Estimated Deep Percolation, Extractions, and Change in Storage, Hydrographic Unit IV (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow: Groundwater Pumpage			Components of Outflow			Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	M & I	Irrigated Agriculture	Total Net Extraction	Extraction by Phreatophtyes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	26.7	0.6	38.5	0.4	49.6	15.4	3.7	154.0	157.7	0.2	0.3	68.4	131.2	226.6	-95.4	-37.4	-95.4	-37.4	248.3
1982	13.7	126%	33.6	0.5	133.4	24.1	46.1	19.1	3.9	66.1	70.0	0.2	0.3	52.2	256.7	122.7	134.0	96.1	38.6	58.7	771.3
1983	16.1	148%	38.2	0.5	122.3	38.4	42.0	35.7	4.2	105.4	109.6	0.2	0.3	73.2	277.2	183.3	93.9	40.8	132.4	99.5	1,402.0
1984	6.1	56%	74.1	0.5	67.3	7.6	57.6	5.3	4.8	161.8	166.6	0.3	0.3	56.5	212.4	223.6	-11.2	-21.3	121.2	78.2	516.8
1985	7.2	66%	36.2	0.5	52.7	4.2	52.0	14.1	4.9	148.8	153.7	0.1	0.3	33.2	159.9	187.3	-27.5	-26.9	93.7	51.3	329.9
1986	13.9	128%	39.3	0.4	97.4	14.9	41.5	29.2	5.2	94.0	99.2	0.1	0.3	29.0	222.7	128.6	94.1	31.2	187.8	82.4	815.0
1987	8.2	75%	39.9	0.6	24.5	0.5	45.8	18.3	5.6	164.7	170.2	0.2	0.3	20.4	129.6	191.1	-61.5	-54.7	126.3	27.7	183.9
1988	9.4	86%	14.2	0.5	31.8	1.0	46.8	10.9	5.0	169.6	174.7	0.2	0.3	26.5	105.2	201.6	-96.4	-64.4	29.9	-36.7	184.5
1989	8.3	76%	7.9	0.6	30.2	0.1	46.4	13.2	6.1	162.4	168.5	0.1	0.3	25.9	98.4	194.9	-96.5	-70.6	-66.7	-107.3	214.3
1990	5.8	53%	21.1	0.5	15.7	0.0	48.2	15.0	6.3	186.3	192.5	0.1	0.3	22.8	100.4	215.7	-115.3	-112.0	-182.0	-219.3	141.2
1991	8.7	80%	21.7	0.5	37.2	0.3	42.3	22.1	6.3	155.8	162.1	0.1	0.3	26.9	124.1	189.5	-65.4	-35.6	-247.4	-254.9	252.3
1992	9.2	84%	40.0	0.5	22.4	0.6	40.3	14.8	6.6	165.8	172.5	0.2	0.3	17.0	118.6	190.0	-71.4	-47.4	-318.7	-302.4	148.4
1993	12.7	117%	34.9	0.5	91.9	7.1	39.4	33.0	6.7	97.6	104.4	0.2	0.3	26.5	206.8	131.4	75.5	44.9	-243.3	-257.4	550.1
1994	7.8	72%	26.9	0.5	29.8	0.8	40.8	12.8	7.2	163.9	171.1	0.2	0.3	26.0	111.5	197.7	-86.1	-17.0	-329.4	-274.4	191.7
1995	17.6	161%	15.9	0.5	112.6	18.2	36.0	43.5	7.5	54.5	62.0	0.1	0.3	29.8	226.7	92.3	134.4	52.3	-195.0	-222.1	866.7
1996	11.5	106%	31.8	0.5	88.7	12.9	35.3	25.6	7.5	99.5	106.9	0.3	0.3	50.2	194.9	157.7	37.2	57.9	-157.8	-164.2	528.7
1997	11.2	103%	44.5	0.5	94.5	12.7	36.2	21.4	8.1	104.0	112.2	0.3	0.3	71.0	209.7	183.7	26.0	23.6	-131.8	-140.7	759.7
1998	22.1	203%	40.5	0.5	101.3	24.8	26.2	70.0	7.9	36.3	44.2	0.2	0.3	44.2	263.3	88.8	174.4	96.7	42.6	-44.0	927.9
1999	9.2	84%	20.1	0.5	43.8	1.2	33.7	37.4	8.1	128.1	136.2	0.3	0.3	47.7	136.8	184.5	-47.8	-60.5	-5.1	-104.5	266.0
Maximum	22.1	203%	74.1	0.6	133.4	38.4	57.6	70.0	8.1	186.3	192.5	0.3	0.3	73.2	277.2	226.6	174.4	96.7			
Minimum	5.8	53%	7.9	0.4	15.7	0.0	26.2	5.3	3.7	36.3	44.2	0.1	0.3	17.0	98.4	88.8	-115.3	-112.0			
Average	10.9	100%	32.0	0.5	65.0	8.9	42.4	24.0	6.1	127.3	133.4	0.2	0.3	39.3	172.9	173.2	-0.3	-5.5			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

Table 75. Estimated Deep Percolation, Extractions, and Change in Storage, Hydrologic Unit V (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow						Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
									Groundwater Pumpage												
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	M & I	Irrigated Agriculture	Total Net Extraction	Extraction by Phreatophtyes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	29.3	3.0	22.7	3.4	53.3	13.1	10.1	154.8	165.0	0.0	0.2	16.3	124.8	181.5	-56.7	-43.9	-56.7	-43.9	248.3
1982	13.7	126%	25.5	3.1	96.7	81.2	50.0	16.8	10.6	48.7	59.3	0.0	0.2	14.6	273.2	74.1	199.1	157.6	142.4	113.7	771.3
1983	16.1	148%	24.8	3.2	97.6	141.3	43.1	33.0	11.1	142.6	153.7	0.0	0.2	33.9	342.9	187.8	155.1	107.6	297.5	221.3	1,402.0
1984	6.1	56%	22.5	3.3	51.2	29.4	61.6	4.0	11.5	146.9	158.5	0.1	0.2	35.3	171.9	194.0	-22.1	-23.6	275.4	197.6	516.8
1985	7.2	66%	15.5	3.4	30.5	12.8	56.0	11.1	12.0	153.3	165.2	0.0	0.2	26.7	129.2	192.2	-63.0	-34.0	212.4	163.6	329.9
1986	13.9	128%	15.4	3.5	84.0	47.4	44.2	22.2	12.5	33.9	46.3	0.0	0.3	31.3	216.6	78.0	138.7	86.4	351.1	250.0	815.0
1987	8.2	75%	14.1	3.6	4.8	1.8	48.7	15.8	12.9	200.6	213.5	0.0	0.1	24.4	88.7	238.0	-149.3	-114.1	201.9	135.9	183.9
1988	9.4	86%	19.5	3.7	24.3	2.1	49.8	10.9	13.2	152.0	165.1	0.0	0.2	5.1	110.2	170.6	-60.3	-80.5	141.6	55.4	184.5
1989	8.3	76%	18.1	3.8	13.4	0.2	49.6	13.3	13.7	179.0	192.7	0.0	0.2	6.7	98.3	199.6	-101.3	-123.5	40.2	-68.1	214.3
1990	5.8	53%	17.5	3.9	0.2	0.0	50.9	13.9	14.7	220.9	235.5	0.0	0.0	7.8	86.3	243.4	-157.1	-160.3	-116.8	-228.4	141.2
1991	8.7	80%	25.2	4.0	18.1	0.3	44.0	18.3	15.3	159.8	175.2	0.0	0.2	6.5	109.8	181.9	-72.1	-80.6	-188.9	-309.0	252.3
1992	9.2	84%	30.6	3.7	7.9	0.2	42.1	13.5	15.2	179.0	194.3	0.0	0.1	2.6	98.0	197.0	-99.1	-84.0	-288.0	-393.0	148.4
1993	12.7	117%	20.1	4.1	67.5	24.6	39.8	29.5	14.8	28.4	43.2	0.0	0.2	10.2	185.5	53.7	131.8	59.5	-156.2	-333.5	550.1
1994	7.8	72%	31.5	4.5	13.2	0.0	41.9	13.6	18.6	163.4	182.0	0.0	0.1	17.9	104.7	200.1	-95.4	-66.3	-251.7	-399.8	191.7
1995	17.6	161%	32.6	4.6	72.4	61.4	36.5	36.3	17.0	38.7	55.7	0.0	0.2	9.3	243.9	65.2	178.7	94.6	-73.0	-305.2	866.7
1996	11.5	106%	17.0	4.6	66.7	41.2	35.9	20.7	18.0	48.2	66.3	0.0	0.3	9.6	186.2	76.1	110.0	8.0	37.1	-297.3	528.7
1997	11.2	103%	9.8	4.7	59.5	39.6	36.4	17.1	18.9	83.7	102.6	0.0	0.2	8.5	167.1	111.4	55.7	66.0	92.7	-231.2	759.7
1998	22.1	203%	22.2	4.7	78.7	84.8	26.1	60.2	15.6	12.8	28.3	0.0	0.2	23.4	276.8	52.0	224.8	108.1	317.5	-123.2	927.9
1999	9.2	84%	29.8	5.2	34.8	3.9	33.0	27.9	19.9	83.9	103.8	0.1	0.2	17.4	134.6	121.5	13.1	-9.0	330.6	-132.2	266.0
Maximum	22.1	203%	32.6	5.2	97.6	141.3	61.6	60.2	19.9	220.9	235.5	0.1	0.3	35.3	342.9	243.4	224.8	157.6			
Minimum	5.8	53%	9.8	3.0	0.2	0.0	26.1	4.0	10.1	12.8	28.3	0.0	0.0	2.6	86.3	52.0	-157.1	-160.3			
Average	10.9	100%	22.2	3.9	44.4	30.3	44.4	20.6	14.5	117.4	131.9	0.0	0.2	16.2	165.7	148.3	17.4	-7.0			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

Table 76. Estimated Deep Percolation, Extractions, and Change in Storage, Hydrologic Unit VI (in 1,000s af)

Calendar Year	Rainfall		Components of Inflow						Components of Outflow						Total Inflow	Total Outflow	CHANGE IN STORAGE		CUMMULATIVE CHANGE IN STORAGE		Kaweah River At 3 Rivers
	Inches	% of Average	Subsurface Inflow	Wastewater Inflow	Streambed Percolation and Conveyance Losses	Percolation of Recharge Basins	Percolation of Irrigation Water	Percolation of Precipitation	Groundwater Pumpage M & I	Groundwater Pumpage Irrigated Agriculture	Groundwater Pumpage Total Net Extraction	Extraction by Phreatophtyes	Evaporative Losses	Subsurface Outflow			Inventory Method	Specific Yield Method	Inventory Method	Specific Yield Method	
1981	8.4	77%	43.9	0.0	16.1	0.5	56.7	12.3	2.0	201.6	203.7	0.0	0.1	0.0	129.4	203.8	-74.4	-60.5	-74.4	-60.5	248.3
1982	13.7	126%	55.1	0.0	53.7	57.4	53.2	15.8	2.3	138.9	141.1	0.0	0.1	0.0	235.2	141.3	94.0	136.0	19.6	75.5	771.3
1983	16.1	148%	44.5	0.0	61.0	90.7	43.9	31.8	2.5	127.7	130.2	0.0	0.1	0.0	272.0	130.4	141.6	132.4	161.2	207.9	1,402.0
1984	6.1	56%	31.3	0.0	41.4	16.6	62.5	6.5	2.7	185.6	188.3	0.0	0.2	0.0	158.4	188.5	-30.1	-21.1	131.0	186.7	516.8
1985	7.2	66%	26.3	0.0	18.1	3.4	57.5	9.8	3.0	194.2	197.1	0.0	0.1	0.1	115.2	197.3	-82.2	-39.4	48.9	147.4	329.9
1986	13.9	128%	34.9	0.0	31.4	23.7	45.5	20.7	3.2	138.9	142.1	0.0	0.1	0.8	156.2	143.1	13.2	57.7	62.1	205.1	815.0
1987	8.2	75%	31.1	0.0	10.0	0.4	49.3	15.9	3.4	193.4	196.8	0.0	0.1	0.0	106.6	196.9	-90.3	-46.6	-28.3	158.5	183.9
1988	9.4	86%	16.8	0.0	7.3	0.4	49.9	11.4	3.4	196.2	199.6	0.0	0.1	0.0	85.6	199.7	-114.1	-44.5	-142.4	114.0	184.5
1989	8.3	76%	17.3	0.0	7.0	0.1	50.4	10.8	3.9	200.6	204.5	0.0	0.1	1.0	85.5	205.6	-120.0	-154.6	-262.4	-40.6	214.3
1990	5.8	53%	26.5	0.0	5.5	0.0	50.6	14.6	4.1	218.8	222.8	0.0	0.1	0.0	97.2	222.9	-125.7	-139.0	-388.1	-179.5	141.2
1991	8.7	80%	32.0	0.0	7.8	0.2	43.5	17.3	4.2	189.2	193.4	0.0	0.1	0.4	100.8	193.9	-93.2	-108.8	-481.3	-288.3	252.3
1992	9.2	84%	13.6	0.0	3.8	0.1	41.6	13.8	4.4	195.4	199.8	0.0	0.1	0.0	73.0	199.9	-126.9	-80.8	-608.3	-369.1	148.4
1993	12.7	117%	30.0	0.0	30.3	11.3	39.1	28.7	4.4	123.7	128.2	0.0	0.1	0.3	139.4	128.6	10.8	-157.3	-597.4	-526.5	550.1
1994	7.8	72%	21.8	0.0	5.1	0.1	41.6	15.7	4.8	192.6	197.4	0.0	0.1	3.3	84.4	200.8	-116.4	219.0	-713.8	-307.5	191.7
1995	17.6	161%	36.0	0.0	45.3	42.9	36.5	34.0	5.3	99.8	105.1	0.0	0.1	0.0	194.7	105.3	89.4	52.5	-624.4	-254.9	866.7
1996	11.5	106%	32.4	0.0	34.2	21.4	36.6	21.7	5.1	130.6	135.7	0.0	0.1	0.5	146.3	136.4	9.8	23.3	-614.5	-231.6	528.7
1997	11.2	103%	28.4	0.0	29.7	26.6	37.1	15.8	5.7	145.0	150.7	0.0	0.1	0.0	137.7	150.8	-13.2	-122.9	-627.7	-354.5	759.7
1998	22.1	203%	22.0	0.0	40.9	58.6	26.1	54.3	5.7	83.7	89.4	0.0	0.1	7.0	202.0	96.5	105.4	131.7	-522.3	-222.8	927.9
1999	9.2	84%	22.0	0.0	14.9	2.7	34.6	28.0	5.7	155.9	161.6	0.0	0.1	11.9	102.2	173.7	-71.5	-98.8	-593.8	-321.6	266.0
Maximum	22.1	203%	55.1	0.0	61.0	90.7	62.5	54.3	5.7	218.8	222.8	0.0	0.2	11.9	272.0	222.9	141.6	219.0			
Minimum	5.8	53%	13.6	0.0	3.8	0.0	26.1	6.5	2.0	83.7	89.4	0.0	0.1	0.0	73.0	96.5	-126.9	-157.3			
Average	10.9	100%	29.8	0.0	24.4	18.8	45.1	19.9	4.0	163.8	167.8	0.0	0.1	1.3	138.0	169.2	-31.3	-16.9			

Notes:
The year 1981 for the Inventory Method is between January and December of 1981.
The year 1981 for the Specific Yield Method is between April 1981 and March 1982.

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Table 77. Summary of Comparative Change in Storage Using the Inventory and Specific Yield Methods
(in 1,000s of afy)

Hydrologic Unit No.	Change in Storage	
	Inventory Method	Specific Yield Method
I	-4.9	-0.3
II	13.2	-3.3
III	-15.9	-3.1
IV	-0.3	-5.5
V	17.4	-7.0
VI	-31.3	-16.9
Entire District	-21.7	-36.0

Inspection of Plate 65 reveals that water supply deficiencies were apparent during the late 1980s. Surpluses, however, occurred during the early 1980s (1982 and 1983) and 1990s (1993, 1995 and 1998). During these periods, seasonal surpluses of between 230,000 afy and 707,000 afy occurred. The periods of water supply surplus and deficiency are generally consistent with the seasonal and cyclic pattern of precipitation and surface water supply that occurred during the base period. For the District as a whole, streambed percolation and conveyance losses were the greatest component of inflow (34 percent), followed by percolation of irrigation at about 29 percent and percolation of precipitation at 16 percent. Plate 64 - Schematic Diagram of Average Annual Volumes of Inflow and Outflow graphically presents the results of the water balance using the inventory method.

6.4.2 Safe Yield

The safe or perennial yield of a groundwater basin is typically defined as the volume of groundwater that can be pumped year after year without producing an undesirable result (Todd, 1959). Any withdrawal in excess of safe yield is considered overdraft. The "undesired results" mentioned in the definition are recognized to include not only the depletion of groundwater reserves, but also deterioration in water quality, unreasonable and uneconomic pumping lifts, creation of conflicts in water rights, land subsidence, and depletion of streamflow by induced infiltration (Freeze and Cherry, 1979). It should be recognized that the concepts of safe yield and overdraft imply conditions of water supply and use over a long-term period. Given the importance of the conjunctive use of both surface water and groundwater in the District, short-term water supply differences are satisfied by groundwater pumpage, which in any given year, often exceeds the safe yield of the District and individual hydrologic units. The District, however, has a very large amount of groundwater in storage that can be used as carryover storage during years when there is little natural recharge. Usable groundwater in storage can generally be defined as the cumulative difference of groundwater in storage from historic high water levels (such as occurred in the District in about 1985 or other comparable earlier periods) to historic low water levels (in about 1994). The cumulative storage difference using the inventory method between these periods (refer to Plate 42) is on the order of 2,500,000 af.

The safe yield of the District is difficult to estimate. This difficulty relates to the inherent uncertainties in the estimates of recharge and discharge. Also contributing to the difficulty is the lack of data to account for the changes of groundwater in storage in the confined "pressure" area of the District. Despite these limitations, there are several methods available to estimate the safe yield under the conditions of water supply and use that prevailed during the 19-year base period.

The first approach assumes that the safe yield is equal to the long-term recharge. Although there are considerable assumptions used to estimate each component of inflow in the hydrologic equation, the data suggest the safe yield of the District is on the order of 590,000 afy (summation of the components of inflow, that is 615,700 afy, less the average seasonal overdraft, which is from about 21,700 to 36,000 afy). Using the inventory method, discharge from the District exceeded recharge by some 21,700 afy over the base period, resulting in a decline in water levels. Imbalances of pumping demand related to patterns of land use over the base period are apparent, which created a progressive lowering of water levels in some parts of the District, particularly the westerly area.

A second method to estimate the safe yield of the District is to compare the annual extractions over the base period to the net changes of groundwater in storage. The resulting graphs provide the rate of extraction in which there is a zero net change of groundwater in storage. Both the inventory and specific yield methods can be used to create such graphs. This method, the so-called "practical rate of withdrawal," is a useful method so long as the coefficient of correlation between annual pumpage and storage changes is sufficiently robust and the calculated seasonal values of inflow and outflow are relatively accurate. For these latter values, a degree of uncertainty exists.

In this study, it is believed that there is reasonable accuracy in the estimates of annual groundwater extractions. Annual storage change estimates are also believed to be reasonably accurate, based on the distribution of wells and frequency of water level measurements in the District. As shown on Plate 65 - Practical Rate of Withdrawal, Entire District, the intercept of zero storage change occurs at an annual pumpage value of about 600,500 afy (inventory method) and 538,700 afy (specific yield method), implying that net annual groundwater extractions at this approximate amount would produce no change of groundwater in storage. Similar plates (Plate Nos. 66 to 71 - Practical Rate of Withdrawal, Hydrologic Unit Nos. I to VI, respectively) are provided for each of the six hydrologic units. A summary of the results is provided in Table 78 - Comparative Results of Practical Rate of Withdrawal, Inventory, and Specific Yield Method.

Based on the above, under the current conditions of development and water supply, it is apparent that the District as a whole is in a condition of overdraft. The magnitude of the overdraft is in the range of about 21,700 to 36,000 afy (inventory versus specific yield method).

Table 78. Comparative Results of Practical Rate of Withdrawal, Inventory, and Specific Yield Method

(in 1,000s of afy)

Hydrologic Unit No.	Practical Rate of Withdrawal	
	Inventory Method	Specific Yield Method
I	24.9	26.8
II	81.9	72.8
III	67.1	72.8
IV	133.3	129
V	141.7	126.2
VI	152.4	154.3
District	600.5	583.7

By comparison, B&E (1972) estimated the magnitude of the overdraft in the District at 89,000 afy under water supply conditions that occurred during the 1934-35 to 1965-1966 period, with water use conditions that prevailed in 1965-1966, and with CVP supplies limited to the contractual entitlements of TID. A safe yield of the District was not advanced by B&E per se, but is implied to represent the average annual replenishment (components of inflow) for their Study No. 5 (conditions of water supply and disposal during the 32-year base period of 1934-1935 to 1965-1966). Average annual water supply during this period was about 518,000 afy, with an average annual storage depletion (occurring solely in Hydrologic Unit No. VI) of about 89,000 afy. Their annual "safe yield" of the District would thus be about 429,000 afy, and is considerably less than the value of about 590,000 afy suggested in this report. The 590,000-afy value is an approximation of the summation of the components of inflow (615,700 afy) less the seasonal overdraft estimate (21,700 afy to 36,000 afy) or the estimate of "practical rate of withdrawal" (Table 78). In this report the average annual depletion of groundwater in storage (Table 77), either 21,700 afy [inventory method] or 36,000 afy [specific yield method] is less than the B&E value (89,000 afy) and is not exclusive to Hydrologic Unit No. VI.

The upper and lower limits of the practical rate of withdrawal to the District, shown on Table 78 (as from about 583,700 afy to 600,500 afy), imply that recharge to the groundwater reservoir is not uniform and, in some sense, the numbers presented are hypothetical. The values of annual replenishment are based upon cultural conditions that continually changed over the base period. Some components of recharge are qualified as "best" estimates. It is accordingly inevitable that a discrepancy would occur between the safe yield value determined using an annual replenishment method and the practical rate of withdrawal method. The annual replenishment value derived for the District as a whole is 615,700 afy, and cannot be taken as equivalent to the safe yield since there has been a progressive decline of water levels and storage depletion in the District over the base period.

As used in this report, the safe yield of the District is the average seasonal amount of groundwater that can be pumped over a long-term period and under a particular set of physical conditions without affecting a long-term net change in the amount of groundwater in storage. The physical conditions are the same conditions that were used to determine the annual storage deficit (or surplus) over the base period. Consequently, the safe yield of the District (and each of the hydrologic units) are equal to the average annual pumpage, less the average seasonal deficit, which in this case is taken as the deficit estimated by the specific yield method. Table 78 presents the values. The safe yield for the District, about 575,000 afy, is accordingly less than the average annual replenishment.

The present overdraft in the District is manifested as a progressive lowering of water levels and such declining water levels are most evident in Hydrologic Unit No. VI. Generally, the decline in water levels in this area are about 5 feet per year over the base period, but this varies widely depending on location, seasonal imbalances in water supply (i.e., wet versus dry cycles within the base period), and where pumping (well fields) is concentrated. The rate of decline in this area is not as severe as predicted by B&E (1972), which was stated at about 10 feet per year, on average. The magnitude of the overdraft by B&E (1972) was considerably greater under future (ultimate) conditions of development, and was estimated at about 110,000 afy. Of this amount, 104,000 afy was predicted in Hydrologic Unit No. VI alone.

It should be noted that water supply to the District over the last 30 years has benefited significantly from the regulation of the Kaweah River system by Terminus Dam. It has also been a generally wetter period in terms of both surface water supply and precipitation (effective rainfall). Overdraft in the District will continue to be expressed as falling water levels, particularly in the western part. In the remainder of the District, water level variations will fluctuate over wider ranges, resulting in an increase in average pumping costs.

CHAPTER 7 - RECOMMENDATIONS

7.1 PHASE II GROUNDWATER MODEL

7.1.1 Model Purpose/Objectives

It is recommended that a basin-wide numerical groundwater flow model be developed for the District. The model will serve as a tool for quantitative evaluation of existing and future hydraulic conditions across the District, including changing groundwater level elevations, well yields, natural and artificial recharge, and associated effects on surface water-groundwater interaction. Specifically, the objectives of the model include:

- Refining uncertain components of the hydrologic budget for the basin;
- Refining estimates of safe yield for the basin;
- Evaluating potential impacts on groundwater levels and safe yield as a result of continued and varied operations and hydraulic conditions; and
- Defining operational options for comprehensive and/or localized management of groundwater use across the District.

7.1.2 Model Development

The groundwater model should encompass the District as defined in this study and include the hydraulic interaction between surface water and groundwater. Specific components of the model required include groundwater flow and the hydrologic budget. To represent these components, it is recommended that the groundwater flow model be based on the US Geological Survey's (USGS) MODFLOW model (McDonald and Harbaugh, 1988). MODFLOW is a modular, three-dimensional, finite difference groundwater flow model used widely for evaluation and management of groundwater resources (van der Heijde et al., 1985).

The model domain should reflect the entire District, with variable grid discretization based on known locations of groundwater pumping and recharge centers across the District. The temporal component of the model should correspond to the base period defined in this study. Data reflecting aquifer geometry, hydrogeologic parameters, well pumpage, recharge, and groundwater quality, as summarized in this study, should be incorporated into the model.

Once these data have been incorporated into the groundwater flow model, the model should be calibrated with respect to historically observed conditions across the District. Specifically, calibration targets such as average groundwater level elevations throughout the base period, annual groundwater level elevations throughout the base period, and the hydrologic budget for the District should serve as targets for steady-state and transient calibrations.

7.1.3 Model Application

A series of operational scenarios should be developed and simulated using the calibrated model. For each scenario, groundwater level declines and estimates of safe yield may be defined for the specific hydrologic conditions simulated. The initial scenario, representing a baseline condition, should reflect a transient simulation with known pumping, recharge, and climatological conditions throughout the base period. Additional scenarios should build on the Baseline Scenario, reflecting changes to one or more hydrologic components of the District. The list of potential scenarios may include:

- Simulation of historical conditions throughout the base period (i.e. Baseline Scenario);
- Simulation of water level and groundwater production cost impacts based on anticipated water demands in the future (i.e. year 2020, 2030, etc.) under current conditions of supply and use;
- Simulation of water level and/or water quality impacts associated with brief extreme drought (mid-1970s drought);
- Simulation of water level and/or water quality impacts associated with sustained severe drought (late 1980s-early 1990s drought);
- Simulation of water level impacts associated with increased pumping in specific areas of the District;
- Simulation of water level impacts associated with the Lake Kaweah Enlargement Project;
- Simulation of water level impacts associated with water conservation, both urban and agricultural;
- Simulation of water level and/or water quality impacts associated with various increased or decreased pumping patterns; (e.g., CID and Melga Water Company alter pumping amounts from various wells/wellfields);
- Simulation of water level impacts associated with additional artificial recharge scenarios; and
- Simulation of impacts/benefits associated with an aquifer storage and recovery (ASR) program in the west side of the District.

In addition, the model may be used to develop specific operational scenarios (i.e. pumping and recharge) in order to address any undesirable trends in water quality and water levels resulting from the above scenarios.

CHAPTER 8 - REFERENCES

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